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THE SCIENTIFIC MONTHLY

JULY, 1924

THE MASTER KEY

By Dr. PAUL R. HEYL

BUREAU OF STANDARDS

SOME time ago an interesting question was raised in conversation among a group of members of the Bureau of Standards. Scientific men are engaged in studies which lead over a wide range, from the very small to the very large; and the question raised was this: In which direction, toward the infinitely small or toward the infinitely great, are we most likely to find the master key to the riddles of the universe?

Some difference of opinion existed among the members of the group as to the answer. I have since asked the same question of a number of other persons, and have encountered a like divergence of view. It is to be said, however, that the majority favor the infinitely small; it is in the microcosm rather than in the macrocosm that most persons believe the best chance of success to lie. Yet the advocates of the other view are by no means lukewarm in its support, or at a loss for arguments in its favor. One upholder of the infinitely large said that he did not see how it was possible for any one to hold the opposite view; and the champions of the microcosm are, I believe, sometimes so enthusiastic as to hold a similar but opposite opinion.

Though doctors disagree in this way, it may yet be profitable for us to spend a little time in the consideration of the matter; for it is in the contemplation of such subjects that we best can develop and extend our sense of perspective. The necessity for specialization that more and more is laid upon all scientific workers carries with it the danger of an increasing narrowness of view. One of the most delightful as well as valuable traits of the earlier investigators of nature was their breadth of vision, their catholicity of interest. With a view that could and did comprise all that was

then known of the physical facts of nature they saw suggestions and hints of relationship which might perhaps long escape the eye of the modern specialist.

It was not an accident that it was the many-sided Franklin who first demonstrated the identity of lightning and electricity; and it was no whim or waywardness of fate that the once seen, never forgotten parallel between gravitation and inertia should have remained hidden from seven generations of diligent investigators to be revealed to one who had never been known as an experimental investigator at all, but who had the breadth of vision to formulate an induction based upon the apparently fruitless experiments of others whose sense of perspective did not disclose to them the true value and interrelation of their negative results.

You have all seen those puzzle pictures in which, we are told, are concealed certain figures, the outline of an animal or of a human face. Though the outline may long elude detection, when once seen it is so plain that we wonder how any one could help seeing it immediately. Sometimes the difficulty in finding the figure is due to a too minute examination of detail; often only by standing off and regarding the general effect is the outline to be discovered.

A good example of how the correlation of large and small scale experimental studies may be fruitful of results, where either alone is imperfect and unsatisfactory, is furnished by the history of the determination of speed of light. The first recorded experiment of this kind was made by Galileo, using lantern signals over a distance of two or three miles. Of course, this failed completely. By a long range research, however, he discovered the moons of Jupiter, which later enabled Römer to make the first determination of this important physical constant.

Still later, the discovery of the aberration of light by Bradley, taken in connection with the then roughly known size of the earth's orbit, gave an independent measure of the velocity of light. As a result, there was perceptible a patronizing tendency on the part of astronomers toward physicists. Said the astronomers: "You students of nature on the small scale are fine fellows for the most part; but when it comes to the measurement of such a distinctively physical constant as the speed of light you have to come out into our laboratory to do it."

It was a century and a half before the physicist could find an answer. Finally, the speed of light was measured over terrestrial distances, and so rapidly did method and technique improve that astronomers were forced to correct their estimate of the distance from the earth to the sun by means of this newly determined value

of the speed of light. The physicists then had, as they thought, the last laugh. Fortunately for the astronomers, one of the fraternity discovered in 1898 a remarkable and unique asteroid, which approaches the earth more closely than any other heavenly body except the moon. By observations on this planet (Eros) the distance of the sun from the earth was determined with an accuracy which exceeds that of the velocity-aberration method by a small margin.

And so the matter stands to-day. Astronomers and physicists have learned to respect each other, and from this league of scientific nations has sprung the fruitful science of astro-physics.

But the workers in the small scale to-day are *par excellence* the students of atomic structure and radioactivity; and it is doubtless the flood of light which these researches have thrown upon the constitution of matter which has caused most persons to look favorably in this direction for the master key to the closed doors of the universe. So fruitful of results has been this study of the infinitely small that it has overflowed its banks, and made important contributions toward the solution of such large scale problems as the age of the earth, the geological cycles of continental elevation and depression and the source of the sun's heat.

In the study of radioactivity we have learned to measure the rate of decay of uranium, and have found the final product of its transformation to be lead—lead which can not be distinguished chemically from ordinary lead, but which shows a measurable difference in atomic weight. Certain uranium minerals containing lead have been analyzed, and the ratio of lead to uranium determined. The lead has also been extracted from the mineral and its atomic weight ascertained, indicating how much of it has resulted from radioactive decay. As a result, it appears that the rock in question is at least 900 million years old.[1]

Geology teaches us that large areas of what is now land were at one time beneath the sea, and, conversely, that land connections formerly existed between England and France; between Europe and Africa at Gibraltar and at Sicily; and between Asia and Australia. There is evidence that similar elevations and depressions have taken place repeatedly in a cycle with a period of millions of years. Joly[2] has lately offered an explanation of this cycle based upon the radioactivity of the rocks of the earth's crust. Assuming the lower basaltic strata to contain the same percentage of radioactive material as is found in those basaltic rocks available for examination at the surface, he finds that the heat developed

[1] Duane, Proc. Am. Phil. Soc., Vol. 61, p. 286, 1922.

[2] Joly, *Phil. Mag.*, Vol. 46, p. 1167, 1923.

in the lower layers is greater than that actually being carried off by conduction in the upper layers. In consequence, the lower strata must eventually melt, and suffer a diminution in density. But because the melted rock makes better thermal contact with the overlying strata than did the solid form, and also because the melted rock is a better conductor (or rather convector) of heat than the solid form, it will now lose heat more rapidly than before, cool and solidify with an increase of density, cracking loose from the surface layers, and again making poor thermal contact. The cycle then begins over again. In consequence of this periodic alteration in density of the underlying strata, the balance or isostasy of continents and oceans is disturbed, and elevations and depressions are produced. For this cycle Joly assigns a period of 40 million years.

Various theories have been advanced as to the source of the heat energy which the sun is expending so lavishly. The contraction theory of Helmholtz[3] was for a long time the best explanation that had been found, but it was never completely satisfactory. Helmholtz regarded the sun as having originated from the contraction, under its own gravitation, of a widely diffused nebula, the potential energy of separation of the parts of the nebula reappearing in the condensed form as heat energy. Helmholtz calculated that a contraction in the present diameter of the sun at a rate so slow that it would require a thousand years to become perceptible to us would account for the present output of solar energy. Carrying the calculation back into the past, he showed that it was possible in this way to account for the present rate of solar expenditure over a period of from 20 to 30 million years. Here lies one of the weak points of the theory, for all evidence points to an age of earth history far exceeding this paltry estimate.

It has been suggested that the sun, like the earth, contains radioactive matter, and that his heat is largely maintained from this source. While no one has as yet detected radioactive substances in the spectrum of the sun, there is abundant evidence of helium, which is known to be a product of radioactive decay and our knowledge of the sun's chemical composition is, of course, confined to his outer layer. The proportion of radioactive material necessary on this hypothesis, while greater than that found in the crust of the earth, is not excessive. Calculating it as radium, two or three parts by weight in a million would suffice.[4] It is more than possible that this may be the principal term in the explanation of the solar energy.

[3] Helmholtz, Popular lecture at Königsberg on the occasion of the Kant centenary, 1854; also Poincaré, "Hypothéses Cosmogoniques," p. 197.

[4] W. E. Wilson, *Nature*, July 9, 1903.

Having thus explained that which is in the heavens above, on the earth beneath and in the regions under the earth, what wonder if the students of the infinitely small should feel a growing confidence amounting to a conviction that in this direction lies the nearest road to the solution of all cosmical problems; that the trail is growing warm; that perhaps but a little way beyond lies the goal of every scientific man's ambition? "What," say they, "have the students of the infinitely large to offer in return that approaches in value and importance that which they have received from us? What light can the macrocosm shed upon the problems of the microcosm?"

The modern conception of the atom as a minute planetary system, with its central nucleus and encircling electrons, has been so fruitful of results in coordinating the facts of chemistry and physics that we are apt to lose sight of the fact that it is founded upon what we may not safely call more than a lucky guess, an assumption justified only by its results. A fundamental postulate of modern atomic theory is that an electron may not permanently revolve at any distance it pleases from the nucleus, but that there are certain prescribed distances called energy levels, any one of which it may occupy, while the intervening spaces are zones of instability. In them no electron may remain; through them it may pass, but as rapidly as possible, and without a stopover. For this remarkable construction no theoretical explanation has as yet been brought forward.

I think that the astronomer, waiting years for a total eclipse of the sun, or for a proper motion to be large enough to measure, must sometimes envy the student of the atomic system, and must wish that the objects of his own study would hurry up a bit. And I think, too, that the student of the atom must sometimes wish that he were dealing with something large enough to see and slow enough to follow, and that he must sometimes cast envious eyes upon the astronomer with his light years and parsecs. And confronted by this mystery of energy levels, the micro-physicist will do well to lift up his eyes and look abroad into the solar system.

Is there an analogue of energy levels in the solar system? I think we may answer in the affirmative. In saying this I have not in mind Bode's law, which prescribes the relative distances of the planets from the sun according to a modified geometric series; for, apart from the fact that no reason is evident for this series, the law breaks down at each end, with Mercury and with Neptune. There are to be found, however, two instances of energy levels with intermediate zones of instability, and, moreover, not without a suggestion of a possible cause, which has not as yet been worked out mathematically

to a satisfactory completion. These instances are found in the rings of Saturn and in the distribution of the asteroids.

The rings of Saturn are known to consist of a multitude of discrete particles, each revolving like a miniature satellite in the periodic time proper for its distance from Saturn's center. This ring system contains several divisions, or blank spaces, in which no particles are visible. Also, the inner portion of the ring system, known as the crêpe ring, is much fainter and more shadowy than the outer portion. In it the particles are evidently much more sparsely distributed.

It has been known for a long time that these divisions occur at approximately those distances at which a particle would have a time of revolution commensurable with that of one or another of Saturn's satellites, all of which lie outside the ring system. Astronomers have not been slow to endeavor to find in this fact a cause and effect relation. An elementary consideration makes it appear that a particle which bears this relation to a satellite may be expected to undergo a cumulative perturbation and be drawn eventually into an orbit of different radius, where, because it is now out of step with the disturbing influence, it must remain for a long time[5]. A closer analysis indicates that the solution is not as simple as this would make it appear.[6] The latest work on the subject, that of Goldsbrough,[7] takes into account not only the influence of the outer satellite, but also the mutual effect of all the particles in the zone in question, and arrives at the conclusion that not only can the divisions in the ring system be explained by the influence of one or the other of the satellites, but that the inner, or crêpe ring, is within the dissipative area of the fifth satellite, Rhea, and that the whole ring system lies in a feebly dissipative area due to the sixth and largest satellite, Titan. In this connection it is interesting to note that certain astronomers have believed that they have detected a progressive fading or dissipating of the crêpe ring.

This explanation of the blank spaces is to-day still fighting for recognition; it has not yet arrived. The criticisms of it[8] are directed not so much against the validity of the analysis as far as it has been carried, that is, to a first approximation, but raise (without answering) the question of the effect of second order quantities over a long period of time. Added weight is given this hypothesis,

[5] Lowell, *Observatory Bulletin* No. 66.

[6] Tisserand, *"Mécanique Céleste,"* vol. IV, p. 420.

[7] Goldsbrough: Phil. Trans. A, Vol. 222, p. 101, 1921.

[8] Greaves: Monthly Notices Roy. Ast. Soc., 82, pp. 356–359 and 360–367; 83, pp. 71–79; 1922. E. W. Brown (spring meeting, National Academy of Sciences, April, 1924) has, however, recently shown that commensurability of period necessarily carries with it instability of orbit.

however, by the fact that the same condition obtains in the system of asteroids which is found in the region between Mars and Jupiter. There are now known something like 900 of these bodies, a number large enough to allow the law of probability free play in their distribution; yet it is a fact that in those regions where the periodic time of an asteroid would be commensurable with that of Jupiter few or no asteroids are found.

In the atomic planetary system we have, of course, no exact parallel to this; for the cause of the zones of instability we must here look, not outward, but inward to the nucleus, whose structure is at present unknown. If there is something about the nucleus which produces a field of force which is slightly asymmetric or directive, and if this asymmetry rotates with a certain period, then we may expect a cumulative perturbation to be exerted upon such electrons as possess a periodic time commensurable with the nuclear period. Such a structure of the nucleus is not difficult to imagine. An elongated, or dumbbell form, with one end much more massive than the other, and the whole in rotation about its center of mass may be expected to produce such an effect. And so incomparably more intense are the accelerations in the atom than those which prevail in the more spacious and leisurely solar system that a minute cumulative effect might remove an electron from a forbidden position in a thousandth of a second, while the dissipative effect of the satellite Rhea upon the crêpe ring of Saturn may require thousands of years for completion. In this respect the contribution of astronomy to the science of the atom reminds us of the slow motion pictures which enable us to follow the flight of birds; only in this case we could wish that the pictures were not quite so slow.

We have considered certain contributions of the very small toward the solution of the problems of the very large, and vice versa; and I think we have seen that neither class of workers can afford to neglect the results of the other; that no one can hope to see his problem in its proper perspective who keeps his eyes upon it alone. Nor can we, when confronted by a cosmic problem of the first magnitude, neglect any field of scientific work in our quest for a hint toward its solution. Such a problem we shall now consider; and it is of interest to note that the only two suggestions that have as yet been advanced toward its solution represent the two extremes of scientific investigation—the very small and the very large. This problem is that which is presented to us by the second law of thermodynamics.

Shortly after the establishment of the principle of the conservation of energy in the middle of the last century, and the recognition of the fact that all the different forms of energy are mutually

convertible one into another, it was also found that such conversions did not work equally well both ways; that while mechanical work or electrical energy could be converted readily and completely into heat, the reverse transformation of heat into other forms of energy could be but partly carried out. Once energy gets into the heat form it is impossible to get it all out again. This purely empirical fact, for which no theoretical necessity has ever been shown, forms the basis of the second law of thermodynamics. A little reflection will show that the consequences of this principle present to us a problem of the first magnitude, as broad and deep as the universe.

The energy of the universe is a restless, troubled sea. Transformation and retransformation, crest and trough of the wave continually alternate; and according to the principle just stated, transformations into heat are complete, while the reverse takes place incompletely. As a consequence, the percentage of the energy of the universe which exists as heat is continually increasing, and at some time, however far in the future, all this energy will be in the form of heat, and all will have come to the same level of temperature everywhere. When this state of affairs is reached farther transformations of energy (as far as we now know) will be impossible; the universe will resemble a great pool of Bethesda, awaiting some influence from without to trouble its waters, to disturb again the level of its vast store of useless energy, and render it once more available. Clausius calls this final state "Wärmetod," (death of heat); and the relentless process of degradation which leads up to it was called by Kelvin the "dissipation of energy."

The ancient myths of our Nordic race speak of the coming of a time when both gods and men shall sink into an endless, dreamless sleep; when upon them all, both in Asgard and upon earth, shall descend the twilight, the evening, the everlasting night. This was called by the old Germans "Götterdämmerung," "The twilight of the gods," and from it is taken the inspiration for one of Wagner's operas. If we wished to express in poetic rather than in scientific language the consequences of the second law of thermodynamics, we could not better do it. Translated into the jargon of the physicist "Götterdämmerung" means "The entropy of the universe tends toward a maximum, and its available energy toward a minimum."

It appears, then, looking into the future, that the activity of the universe is steadily approaching a condition of stagnation; but what does this principle tell us of the past? Year before year, the percentage of energy existing as heat must have been less and less, until at some time, however remote, none of the energy was in this

form. And what of the year before that? Was the state of affairs constant, or did a small portion of energy exist as heat? If the latter was the case, then this must have been just before the second law of thermodynamics was placed upon the statute books. If the former, then the universe presents itself to us after the similitude of a clock, wound up, but perhaps not allowed to run for a while; but when finally released, running down, steadily and relentlessly, after its own laws; and with each hour it strikes a different scene presents itself. There was that matin hour, the fresh dawn of creation, when the morning stars sang together, and all the sons of God shouted for joy. There is now the high noon of life and activity and pleasure and pain; and there is coming that vesper hour of twilight, that "Götterdämmerung," when the restless waves of energy shall have quieted down to a dead, dark level forever.

Beautiful and poetic as this may be, there are minds to which it is not satisfactory; minds which can not regard the activity of the universe as comprised between a catastrophic beginning and an asymptotic ending, but which rather regard that portion in which we now find ourselves as but an element of the down slope of some great sine curve; minds which look beyond the approaching minimum to the beginning of a new up slope; beyond the twilight of the gods to the dawn of a new morning; which look back beyond that maximum point in the past to the older up slope which preceded it.

Perhaps we are wrong in this way of looking at the matter. Perhaps we are so accustomed to the endless rhythm and cycle that we see about us, darkness and daylight, evening and morning, summer and winter, seed time and harvest, that our whole mode of thinking may have been unconsciously molded after this pattern. Perhaps, again, we are right. The fact remains that there are scientific men who refuse to accept the second law of thermodynamics as always and everywhere true; who regard it rather as of local and temporary signification, as an expression of conditions which prevail in our immediate region of space and time; who feel that opposite conditions must have prevailed at some time in the past, and will again prevail at some time in the future; nay, more, that perhaps even now, elsewhere in the cosmos, may actually hold sway. Two suggestions of this sort have been put forward, by men whose names command serious attention—Maxwell and Arrhenius.

Maxwell's suggestion was drawn from the infinitely little—the molecular kinetics of gases.[9] Metaphysical though it may sound,

[9] "On the limitation of the second law of thermodynamics;" Appendix to Maxwell's "Theory of Heat," page 328 (1875 edition).

it is as legitimate a deduction from gas theory as is (for instance) the calculation of the mean free path of a molecule. Maxwell regards the downhill action of the second law of thermodynamics as due to the absence of a guiding intelligence, like the actions of a horse whose driver has dropped the reins. Maxwell shows how it is possible to-day for an intelligence endowed with a sight sufficiently keen and a touch sufficiently delicate to effect the handling and sorting of single molecules (and since Maxwell's day we have made a long step in this direction) to reverse the action of this law, to increase the temperature of one half of a mass of gas by withdrawing heat from the other half, to make heat run uphill, to rewind the clock, to place us on the up slope of the curve—and all without violating the principle of the conservation of energy.

In a gas at what we consider uniform temperature all the molecules have not the same velocities, their different speeds being grouped about a mean value according to a law of distribution closely resembling the well-known probability curve. This is a condition of stable equilibrium, to which every other distribution of velocities must in time revert, due to the interchange of velocities by oblique collisions at all possible angles. The whole matter hinges upon the stability of this system of non-uniform velocities. If we in any way could separate the more rapidly moving half of the molecules of a gas from the less rapidly moving half, each set of molecules would promptly redistribute its velocities about a mean, one mean value being higher than the other; and from a mass of gas at uniform temperature we would thus have produced two portions, one hotter and the other cooler than the original mass.

Maxwell imagined a gas divided into two parts, A and B, by a partition containing a great many small, massless doors, each in charge of an intelligence, or, as he quaintly called it, a "demon," with instructions to open his door whenever he saw one of the more rapidly moving molecules in A headed his way, and to keep it closed against the slower ones. Similarly, he was to allow to pass from B into A only the slower molecules. Thus the original set of molecules would, without the expenditure of any work, be sifted into two classes, the more rapid ones accumulating in B and the slower ones in A. The restorative action of collisions would again produce velocities in A nearly as fast and in B nearly as slow as those which had been lost, and the process is capable of limited repetition, ceasing to be useful when the most rapid of the slow molecules are equal to the slowest of the fast molecules.

The temperature of the hotter portion of gas may now be allowed to come to the lower level, driving a heat engine in the process, and

a certain amount of work recovered. The sorting may then be repeated, and more work recovered. All this recovered work, it is to be noted, will have come originally from a mass of gas at uniform temperature, which is cooled in the process.

The suggestion of Arrhenius for avoiding the stagnation which threatens the universe does not require the interposition of intelligence. His suggestion is drawn from the very large. Strutt's work on the radioactivity of the rocks of the earth's crust leads to the conclusion that if radioactive material were distributed in the same proportion throughout the whole mass of the earth there would be generated about 30 times as much heat as is now being lost by radiation from the earth. Two positions are open: we may assume that all the earth's radioactivity is confined to a surface layer about 40 miles deep; or we may suppose it uniformly distributed, but for some reason inactive at greater depths. Arrhenius suggests that the enormous pressures in the earth's interior inhibit radioactive transformations,[10] an idea which may at first appear strange; for we have been taught that radioactivity is something which no forces that we can bring to bear can alter.

It is true that such pressures and temperatures as can be conveniently obtained in our laboratories are powerless to alter radioactivity; but we can not exert anything like the pressure to be found in the earth's interior, nor produce a temperature that approaches within many orders that which must exist inside the sun or the stars. And it is theoretically possible that a pressure high enough might completely stop radioactive explosions of molecules.

But Arrhenius goes a step farther, and suggests that perhaps at pressures and temperatures sufficiently high, radioactive bodies may be regenerated from their decomposition products. For this purpose pressure alone would probably not be sufficient. It is one thing to force a helium atom back into the molecule whence it came, and another to provide it with the great energy it had when it was ejected. Here we need temperatures higher than we are accustomed to think about. To raise a mass of helium to such a temperature that, say, one per cent. of its atoms may possess a speed of one fifteenth that of light (an ordinary velocity of ejection) would require us to reach a temperature of over a billion degrees. The highest temperature at present ascribed to the outside of a star is perhaps 25,000 or 30,000 degrees, but the temperature at its center is classified by Jeans[11] as at least "millions." Without pressure, such temperatures might be expected to have a dissociat-

[10] Arrhenius: Das Werden der Welten, 1907; English Translation, "Worlds in the Making," 1908.

[11] Jeans, *Nature*, March 1, 1924, page 330.

ing effect; but with sufficient pressure it is conceivable that the reverse may happen.

Be this as it may, these two suggestions, drawn from the study of the large and of the small, are the only attempts that have ever been advanced toward a solution of the problem of the death of heat, and the dissipation of energy.[12] Other and better explanations may perhaps replace them; for it is difficult for many minds to conceive of our rhythmic, cyclic universe beginning abruptly and ending in stagnation. For this puzzle the key is yet to be found.

It has always been a favorite idea with me that no one is too old or too grown-up to be interested in a real, good, old-fashioned fairy story. I have demonstrated this to my own satisfaction many times; and, by your leave, I will demonstrate it to yours.

Once upon a time there was a prisoner. His crime must have been great, for he was confined in a cell without windows, where the darkness was relieved only by a faint light that came through a panel of some translucent material in a door in the eastern wall of the cell. The other three walls contained doors also, each different in form from the rest. The door of the south was hot to the touch, and warmed the cell by its radiation. The door of the west contained an always closed wicket with a shelf before it. The prisoner had learned that if (and only if) when he lay down to rest this shelf was duly swept and prepared, would he find upon it when he awoke in the morning his daily material necessities. But the door of the north was most wonderful, for about it a bluish glow played, and from it crackling sparks darted forth to meet the approach of an incautious hand.

How long the prisoner had been in this place he knew not. All his memory was of this cell. He spent much of his time in work, for in the years of his stay he had fashioned a set of rude tools from the débris that littered the floor of his cell. Day after day he would spend at his bench, making keys; for this was his hope—that he might some day make a key to fit one of the locks in the doors of his cell. He would spend weeks over a single key, only to find it useless; then he would throw it upon a pile which already contained many such discarded keys, and set to work patiently upon another.

One night, fatigued, disappointed and discouraged, he lay stretched upon the floor of his cell in slumber. And in his sleep he had a dream; for it seemed that there was in his cell an angel who took from his girdle a key of strange and yet simple form, to which

[12] Very recently (*Am. Math. Monthly*, March 1924) Lotka has put forward a third suggestion of a novel and profound nature, based upon statistical mechanics.

all the four locks yielded. And the prisoner saw in his dream that the four doors were bound together without by a great chain, reaching from door to door, and encircling the cell, so that unless all the doors were opened all must remain closed. And as the prisoner tried in his dream to see what lay beyond he awoke, to find the doors closed as he had always known them.

Then the prisoner turned to his bench and began shaping a key after the fashion of that which he had seen in the hand of the angel. He had had but a fleeting glimpse of it, and had caught but the general plan; the details had escaped him. Finally it was finished, to the best of his recollection, and with a trembling hand he tried the key in the eastern door.

The key turned, although with difficulty. At one point the prisoner had to put forth all his strength to make it pass one of the wards of the lock; yet it passed, and the bolt yielded. With a shout of joy the prisoner pushed the door outward.

It opened but the merest crack, and a blinding light filled the cell. The prisoner shut his dazzled eyes, and felt through the crack with his fingers. His dream was true; there was the chain which prevented it from opening farther. Greatly excited, he withdrew the key, and hastened to the door of the north; but here the key would turn but part way, try as he would; so back to his bench went the prisoner and worked away patiently at the key.

Days of work and trial followed before the key would turn in the north door; yet it finally turned, and the door yielded enough to show the binding chain as with the other. But in the door of the south the key would not turn at all; so back to his bench again went the prisoner and filed patiently at the key.

And lo! as he worked, through the partly opened eastern door there shone upon him a beam of the outer glory; and his heart was glad, and he sang as he shaped the key.

THE ORIGIN, NATURE AND INFLUENCE OF RELATIVITY[1]

By Professor GEORGE D. BIRKHOFF
HARVARD UNIVERSITY

V. Some Relativistic Paradoxes and their Explanation

A first and insuperable paradox of the new theories is often seen in their abandonment of absolute simultaneity; it is taken to be self-evident that either two events are simultaneous or one happens before the other, and it is vigorously contended that the significance of such a statement has nothing to do with the particular method adopted for measuring time.

Very similar feelings must have been aroused when the opinion that the earth was round and not flat was first advanced, for everyday experience as well as primitive cosmogonic speculation seemed to require such flatness. In order to remove the appearance of paradox in the new hypothesis, a first step was to observe that "down" means merely "towards the earth," and need not refer to a fixed direction in space, although very nearly the same direction for long distances. Undoubtedly, a distinct mental effort was required in granting as much.

In the same way, even after the relativist points out that simultaneity obtains a genuine meaning only by reference to some system of time measurement, it is not easy to give up the belief that simultaneity is an absolute affair, and that clocks everywhere are to be adjusted so as to run in unison.

A further step was available to convince the skeptical but intelligent inquirer that the earth was spherical, namely, to inform him about the truths of geometry and the observed difference in apparent position of the sun at any two places remote from one another on the earth. Likewise, the new analysis of the concepts of space and time, and facts such as the Michelson-Morley experiment, open the way to an understanding of relativity.

The salient feature of the special theory of relativity is that all undisturbed bodies are held to be equally satisfactory for setting up systems of space-time reference. It can not be expected that the facts observed to transpire in any particular system so obtained have an absolute physical meaning; by their very nature they must be facts affected by their relation to the arbitrarily selected reference body or "particle," as we shall call it. In consequence, there

[1] Lowell lectures.

is no *a priori* basis for the identification of the facts as stated for different particles.

The apparent paradoxes of relativity are largely due to a confusion of distinct systems of space-time reference. On this account they are easily explained after suitable consideration has been given to the nature of the correlation between the various systems.

There are, of course, many results which may be stated independently of the arbitrary reference particle. For example, if light flashes back and forth along a meter stick, a perfectly definite interval of local time will elapse meanwhile on a clock attached at the end of the stick whatever its apparent velocity may be.

This is the essential physical truth embodied in the so-called hypothesis of the constancy of the velocity of light, and makes it possible to measure the natural dimensions of a body by optical signaling between its points.

On the other hand, the simultaneity of two events has only a precise meaning in relation to the particular reference particle selected. Thus, if a reference particle P is the midpoint of a meter stick, a light flash from P will reach its two ends simultaneously in P's system of space-time measurement, by the very definition of simultaneity. Now imagine a second stick which is moving relatively, the midpoint Q of which is superposed on P at the instant when the light flash starts. It is clear that (for P) the light flash will reach the approaching end of the moving stick before it reaches the receding end. In other words, the flash will not reach the ends of the moving stick simultaneously in the time system of P. But in the system of the midpoint Q of the moving stick, these two events will be simultaneous, of course.

Similarly, there is no reason to expect that the optically determined length of a meter stick in motion relative to a reference particle will be a meter which is its natural length, or that a moving clock will tick once every second in the time of a reference particle. The determination of what the facts are will depend on the selection of definite technical means for measuring the space and time of the reference particle, together with the correlation of these spaces and times in accordance with the hypothesis of relativity.

The surprising extent to which the statement of the results in the old or new theories depends on the particular technical means of measuring space and time may be brought out in a suggestive way as follows:

Suppose that a dark star enters the solar system with a velocity nearly that of light, and becomes luminous in so doing. A terrestrial observer will *see* it approach with a velocity greatly exceeding that of light. This is obvious, since if its velocity were

equal to that of light, the star would strike the earth without ever becoming visible. The apparent paradox disappears, of course, when the proper allowance is made for the time which light from the luminous star takes to reach the earth.

Henceforth it is to be understood that the space and time used are not those of events as seen at the reference particle, but with this time correction allowed for.

The relativistic correlation of the spaces and times of various reference particles is very much like that to be found in some ordinary correlation problems, which can be more readily grasped, and which will be referred to first.

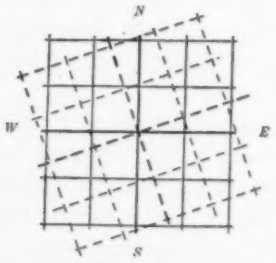

FIG. 1

Suppose that the squares of a projected city are laid out, but not exactly from north to south and from east to west because of topographical difficulties. Suppose further that it is subsequently decided to run the streets differently, say inclined at an angle of 20° to the directions first chosen. It is apparent from the figure that there will be no obvious relation between distances east and north, as measured in the two arrangements.

The easterly distance and the northerly distance between points of the city, as obtained in the two ways, are comparable to space distance and time difference between events for two reference particles in relative motion. Taking events which are simultaneous for one particle to be simultaneous for the other also, is akin to taking points on the same east and west street of the original arrangement as likewise so in the modified one. More generally, taking the distance or time between two events to be the same for both reference particles is like assuming that the distance by which one point is east or north of another will be the same whichever way it is measured.

The following problem in correlation is even more analogous to that found in relativity. Suppose that the surface of the earth is mapped on a plane by some specific method. The parallels of latitude and the meridian circles will then take definite positions (the circles and the straight lines in figure 2). Instead of the

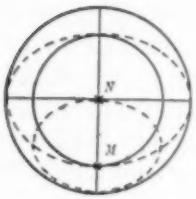

FIG. 2

north pole *N*, some other such pole can be selected, say the pole *M*. By the same method, a second map is obtained which will be quite different in appearance from the original map. If, however, the new parallels of latitude and circles of longitude are drawn on the first map, it will be possible to use them for drawing the second map. Here also is a problem in two-dimensional correlation.

There is no simple rule of correlation between the latitude and longitude of a point as measured on the two maps, and the fact serves once more to illustrate what may be expected when the various spatio-temporal systems of relativity are correlated.

A simple case of that theory is presented by particles moving on a single spatial line. A variety of particles are then directly approaching or receding from one another in empty space. To each of these there is attached a space and time found by light signaling methods. Thus, if a light flash is sent out from a reference particle *A* and returns by reflection at some second particle *B* after two seconds, then the event of the reflection is specified in space and time by the two observations at *A*. The space and time referred to is that of the particle *A;* as stated previously, the accepted technique of determination of these measurements is identical with that used in the classical theory when the reference particle *A* is "absolutely at rest." Since the light flash travels the same distance either way, the distance of the event signaled from *A* is one light-second. The time of the event will be one second after the light flash was sent out from *A*.

The collection of all these events is clearly two-dimensional, with one spatial dimension and one temporal dimension.

If an "observer" at *A* were to collect observations of events, he would naturally employ a chart in which one direction indicates distance from *A*, and the perpendicular direction indicates time of happening. Such a chart serves to specify events in the same way as the plane map serves to specify the points on the earth's surface. It is to be expected that the representation of events obtained is imperfect, but so is that given by a plane map of the spherical earth. In fact, the physical reality of lapse of local time

between two events at an arbitrary particle is imperfectly represented by distance in the chart, just as the physical reality of distance between two points on the surface of the earth is not represented exactly by distance on the map. For the map, the distortion is least near the poles and greatest near the equator. With the charts, a considerable distortion is found only in the case of relative velocities comparable to that of light.

Moreover, in the same way as with different choices of a pole on the earth various maps are obtained, so all the various particles yield corresponding charts. These charts will be essentially the same only for particles relatively at rest.

There is another analogy which is worthy of note. All the parts of a sphere are alike from a geometrical point of view, and yet this identity of properties is masked when the sphere is mapped upon the plane. Similarly, it is a fact that space-time is the same physically for every reference particle, and yet this is not obvious from a casual inspection of a single chart. It is desirable now to outline briefly how there can be complete relativity of this kind with respect to any reference particle, without essential paradox.

Assume that a definite particle A is selected, and that in its space and time, determined by the particular light signaling process specified above, every other particle travels with a constant velocity less than that of light, the latter velocity being unity on account of the fact that the light-second is taken as unit of distance in defining the space and time of the reference particle. This assumption means that the events at any observed particle B are represented by a straight line on A's chart.

Thus far, the only clock used is the one at A. The clock at a particle B in relative motion can be arbitrarily assumed to go at any assigned rate, and a moving measuring stick to vary in length for A according to velocity, and still no inconsistency can arise, for all the hypotheses are mutually independent.

Suppose in particular that any three Pythagorean numbers such as 3, 4, 5 (so that $3^2 + 4^2 = 5^2$) are selected. If we desire, the specific assumption about the behavior of clocks and measuring sticks may be made that, if the velocity in A's space and time is three fifths that of light, then the slowing down of clocks and the contraction of measuring sticks will be in the ratio of 4 to 5. We may extend this rule to any set of three Pythagorean numbers such as 5, 12, 13. In such a way there is obtained a purely hypothetical space-time, which is bound to be self-consistent by its very manner of definition.

At the reference particle B it is possible to imagine the same signaling process carried out, in order to obtain B's system of space-time reference. It will then be found as a result of easy

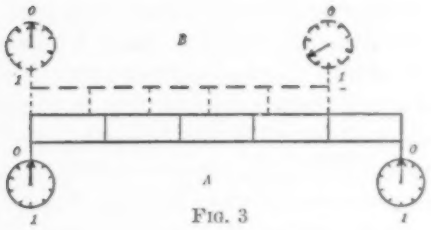

FIG. 3

algebra that the relation of A's space and time to B's space and time is exactly that of B's to A's. By the use of the same method it is also possible to find the interrelation of the space and time of a particle C to B's, by the intermediation of A's space and time. Exactly the same Pythagorean rule is found in this way to hold for B as well as for A. Hence the self-consistency of relativity follows. It may be observed that if clocks and measuring sticks do not behave as required by the Pythagorean rule, the principle of relativity does not hold.

The adjoining figure illustrates an optically determined position of a measuring stick B of one light-second in length which is moving to the right at three fifths the velocity of light relative to the reference measuring stick A whose natural length is also one light-second. It will be observed that B's optical length is only four fifths that of A. The clocks attached to the two ends of A point to the same zero of time, since a single instant of A's time is represented. The clock attached to the left-hand end of B is also taken to point to the zero of time; it will be noted that then the clock at the right-hand end of B has a lag of three fifths of a second, in agreement with the fact that events simultaneous for A will not be for B.

After one second has elapsed at A, the stick B has moved three fifths of a light-second to the right of course, and has still the optical length of four fifths. It will be seen that the same characteristic lag is found in the clocks at B, and that these have only run four fifths of a second for A.

A possible difficulty may be felt in the fact that the stick B in

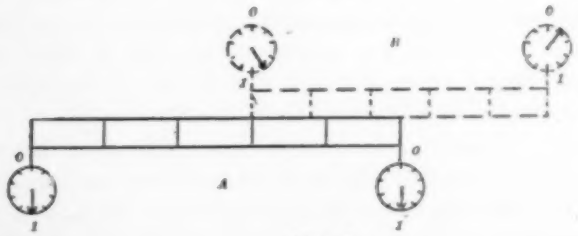

FIG. 4

motion is deemed shorter than the stick A at rest, while, if B is taken to be at rest, A is held shorter. Such a difficulty only arises from the attempt to overlook the difference between the reference systems attached to A and B, and treat them as identical. A glance back at the two sets of streets of the hypothetical city (Figure 1) shows that the easterly distance between a pair of north and south streets of the second arrangement, measured in the first, exceeds that between a pair of north and south streets of the first arrangement, and that, notwithstanding, the same is true when the rôle of the two arrangements is interchanged. This analogy indicates the lack of ground for the stated difficulty, or for any similar difficulty in the behavior of clocks in relative motion.

After these preliminaries we are fully prepared to deal with some amusing and instructive relativistic paradoxes, the explanation of which illustrates various results of the theory.

The Quest of the Absolute

Despite the *dictum* of relativity, may it not be possible to define absolute space and time? The method to be proposed can be best understood after its analogue in Newton's theory for determining an "absolute space" has been formulated.

According to the Newtonian laws, the center of gravity, C, of the sidereal universe moves with uniform velocity in a straight line. The "absolute" space may be taken to be that attached to a hypothetical particle at C. In other words, the absolute space is the particular one for which the center of gravity is at rest. It is for this space only that the motion of matter everywhere is most symmetrically distributed in direction, and that the total energy of motion is least.

In the special theory of relativity it is possible to proceed by a somewhat more involved but entirely similar method, to define an absolute space and time. It is simplest to do this when there is a set of mass particles in uniform rectilinear motion. Then there can be found a hypothetical reference particle C, for which the attached space and time have a peculiar property, namely, that there is no "apparent momentum" in any direction. It is again a system of reference for which the motion is symmetrically distributed in all directions. When there are only two particles of equal mass, C will lie half way between them at rest in the absolute space. If the mass particles are interacting, it is still possible to obtain a hypothetical particle C, such that for any event E at C, some particle D at the event has the symmetrical distribution of motion sought. Here we may define the absolute space as that of D at E, and absolute time as given by the clock moving with C. The main

fact to observe is that, despite the increasing complexity of definition, the space and time called absolute can be chosen by a symmetrical method. Even in the general theory of relativity it is possible to proceed similarly, since it is known that the space of a particle at an event can be uniquely defined.

The fundamental objection to any definition of this sort is that the most convenient statement of physical law is accomplished without any use of such an absolute system of reference. It is true that the absolute space and time specifically proposed present a further difficulty, namely, that large quantities of matter, so extremely remote from the sidereal universe as not to be observable, might greatly modify the space and time called absolute, which seems unreasonable. But mere intellectual convenience is the major consideration requiring the abandonment of an artificial absolute space and time.

The essential meaning of relativity is thus that the laws of nature are most easily stated in terms of systems of space-time reference not uniquely defined.

The Clock Paradox

The following paradox is often baffling. Two clocks K and L are at a particle P. If the second clock is moved in any manner away from P and then back again, it will be found to have gone more slowly than the first clock, although the rates will still be the same at the two comparisons. However, the situation seems entirely reciprocal. In the same process, the first clock leaves the second and is then brought into coincidence with it again. It appears as if not only L registers less time elapsed than K, but also K registers less time than L. Now such a state of affairs is obviously impossible.

The answer to the paradox is that only K remains in undisturbed motion at P. By the stated rule, it is clear that L will go more slowly than K, so that less time will elapse at L. Since the motion of L is disturbed, it can not be taken to coincide with a reference particle during the process. If L were not disturbed it would necessarily remain in coincidence with P. Thus the reason for the apparent paradox lies in a deceptive appearance of symmetry between the two clocks.

The Age of Light

Astronomers tell us that light arriving from a very distant star is extraordinarily old. But, according to the theories of relativity, light is ageless. In fact, imagine a clock traveling as fast as light. The Pythagorean rule shows that the corresponding Pythagorean

triplet is 1, 0, 1. Hence, contraction of measuring sticks to *nil* and a complete stopping of clocks takes place in motion with the velocity of light. Since the clock at the light wave is not going, the wave can not age at all. More precisely, we may imagine that the clock travels at a rate slightly less than that of light; then, in the reference system attached to this clock the aging of the light will be very small while the light leaves the distant star and travels to the earth. Of course the apparent distance from star to earth will be greatly reduced for such a reference system, as obtained by the optical method. The conclusion follows that the age of a light wave is entirely relative to the particular space and time of reference selected.

For the astronomer the reference space and time selected is that attached to the sun and the fixed stars. It is in this sense that the usual astronomical statement has meaning.

An Adventure in Time and Space

The episode which we now propose to tell is one which seems at first to transcend the imagination, and yet which is entirely in order for the relativist.

A youth, bidding farewell to his companions, enters a properly constructed projectile and is hurled away from the earth with a velocity nearly that of light. (As a matter of fact it would require at least a month of constant high acceleration to acquire safely such an extraordinary velocity.) The projectile is directed toward an enormous star thirty light-years distant. On approaching the star, its gravitational attraction is used to reverse the direction of the projectile, and he returns safely to the earth. For him the entire journey will take a very short time and he will still be young. Yet his companions will have become old men.

This paradox is explained just as the preceding one was. Relative to the earth, his clock will tick off the seconds very slowly, and his physiological activities will go on at a proportionately slow rate. If we undertake to specify what happens relative to the daring youth, we are no longer on familiar ground, since the projectile is not in undisturbed motion during its entire flight.

It is interesting to inquire what would be "seen" to transpire through suitable telescopes. From the earth events would appear to happen very slowly at the projectile on its sixty year outward journey at apparently only half the velocity of light. Then the projectile would be seen to shoot back with an incredible velocity greatly exceeding that of light, and would reach the earth in a very short time during which events in the projectile are observed to happen very rapidly. The youth would undergo a still more

curious experience. In particular he would see the apparent distance between the earth and star become very small, while their apparent diameters would be unaffected.

The Speed Paradox

It has been stated that the velocity of a particle can not exceed that of light in relativistic space-time. But why can we not proceed as follows? Consider a first particle P, moving in one direction with two thirds the velocity of light relative to Q, and another particle R, moving in the opposite direction with the same velocity relative to Q. Then it would seem that the velocity of R relative to P is four thirds that of light.

It is clear that this conclusion involves the assumption that the velocity of P relative to Q and the velocity of R relative to Q will combine to give the velocity of R relative to P. But what is really obtained by this addition is the velocity of R relative to P *in the Q system of reference*, and not in the P system as desired. Thus, this paradox, too, is explained by the confusion of reference systems. As a matter of fact, the velocity of R relative to P will be only twelve thirteenths of that of light. The same process may be indefinitely continued for any number of particles, each of whose velocities relative to its predecessor is two thirds that of light; and yet the velocity of the last particle relative to the first will still be less than that of light. The mathematical formulas justify this remarkable conclusion.

Is Mass Constant?

In classical physics mass is a constant. If a force, say equal to only one pound, is constantly exerted on a pound of matter in empty space, its velocity will exceed that of light by the end of a year. But this can not happen in the theory of relativity, since no velocity can exceed that of light. The only possible conclusion seems to be that the mass increases as the velocity does. Hence mass seems to be at once constant and variable.

To explain the paradox, let us suppose the force to have acted for only one second. The mass will possess a certain velocity (about 32 feet per second) relative to the initial reference system. Adopt now the reference system for which the mass is at rest at the instant. Since the conditions are exactly as they were at first, the velocity will be increased relatively by the same amount as before during the next second, and this will continue indefinitely.

But, as we observed in the discussion of the preceding paradox, it is not possible to make the velocity equal that of light by such a process. Consequently, the velocity will increase indefinitely, but never can become as great as that of light.

Hence in the first reference system it will appear as though the mass were responding less and less readily to the action of the force. The "apparent" mass may then be said to increase, although the "natural" mass of one pound remains unaltered.

The fact that increase of apparent mass occurs with increase of apparent velocity is often stated in the more specific but not quite exact form that increase in apparent mass is equal to the increase in kinetic energy.

Is Space Curved?

It has been pointed out that in the special theory of relativity, empty space is flat or Euclidean. It is often said that in the general theory, space is curved because of the presence of matter. What is the meaning of this statement?

A curved space is one in which experiments in spatial measurement are not in accord with ordinary geometry. For example, on the surface of the sphere, distances and angles obey different laws than in the plane. Hence the sphere is curved.

By the general theory of relativity, there is not usually to be found the stationary condition essential for comparative spatial measurement. However, the solar space attached to the sun happens to be nearly stationary, since the planets only disturb the sun slightly. It turns out that the solar space so obtained is curved, so that, for instance, the ratio of the distance around a circle with its center at the sun to its distance through is not exactly the ratio of ordinary geometry.

Of course distance may be defined anew so that the space about the sun is Euclidean, in the same way as distance on the sphere may be defined as distance on a plane map of the sphere. But such distance will not then be that determined by the use of the measuring stick in space, and lacks physical significance.

Is Space Finite?

It follows in Einstein's general theory that if the density of matter does not diminish indefinitely at great distances, then the spatial universe is finite in extent. This seems very paradoxical at first. However, if we imagine a thoroughly two-dimensional being, somehow confined to move in the surface of a very large sphere (to him like a plane), then his spatial experience will be two-dimensional just as our own experience is three-dimensional. Moreover, to him space will appear not only unbounded, but infinite, whereas in fact it is unbounded and finite. This familiar illustration is sufficient to make it conceivable how space may be unbounded, and yet finite in extent.

At present the astronomical evidence does not point to the finiteness of space.

This completes the selected list of paradoxes. It has appeared that nearly all these apparent paradoxes have arisen because of a confusion of different systems of space-time reference. Yet it is possible and convenient to hold fast to a single arbitrary system of reference, provided only the arbitrariness be recognized. In the same way, position on the earth is defined once for all in terms of latitude and longitude, which involves the arbitrary initial choice of a pole of reference. Despite the fact that an arbitrary method of earth measurement is selected, no one feels obliged to consider the interrelation of two systems of reference obtained by selecting two poles. Of course the alikeness of the sphere in all its parts and in every direction, and the fundamental importance of the concept of distance, are admitted, and the distortion of distances on the map because of the selection of a particular pole is expected.

Similarly, in dealing with a particular physical problem, it is desirable to adhere to a definite means of space-time measurement, while the alikeness of space-time throughout, as embodied in the principle of relativity, and also the fundamental nature of the interval of local time between events, are recognized. Peculiarities observed in the behavior of clocks, measuring sticks, etc., are accepted as only natural, for it is understood that these phenomena represent a kind of apparent distortion relative to the selected reference body. In this way it is easy to arrive at a satisfactory mental attitude toward the new doctrines.

THE MISSISSIPPI GULF IN THE MIDDLE AND UPPER EOCENE

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In previous numbers of this journal I have given accounts of the Mississippi embayment during the Upper Cretaceous and Lower Eocene.[1] The approaching publication of a long delayed monograph on the middle and upper Eocene floras of southeastern North America[2] seems an appropriate time for giving a popular account of some of the outstanding items in the history of this interesting region during those times.

There is a perennial fascination in all history, and this is especially true of the history of the earth—eons old and ever young. Like the humble peasants passing their lives over the buried sites of some powerful city of antiquity, most of us are inclined to think of the present as having come down to us unchanged out of the distant past.

As the Bedouin may roam over the sites of Nineveh or Babylon and know them not, or the rude fisherman of Joppa know not of Tyre, or the peasant Turk have ever learned of Troy or Sardis, so we may pass our lives on the site of countless dramas of the past without ever a realization of the wonders buried in the ground beneath our feet, and this is more true of geology than of archeology, for everywhere that man lives he lives on the surface of a buried earth history.

The region of the lower Mississippi Valley and the states bordering the present Gulf of Mexico is one that is physiographically unique; it rivals the Paris Basin in the unity of its geologic history, in its stability in altitude, and in the abundance of its alternating marine faunas and terrestrial floras. Because of its large size, its proximity to the American Tropics, and its long, uniform and relatively unbroken geologic record, its fossil plants also furnish unique and invaluable suggestions as to the evolution and geographic distribution of floras. During the whole of the Tertiary period it was the low-lying southern part of a continental land mass that was bordered on the south and southeast by an ocean, so that its meteorologic conditions were comparatively uniform. Throughout its long

[1] Berry, Edward W., SCIENTIFIC MONTHLY, Vol. 4, 1917, pp. 274–283, 8 figs.; Vol. 9, pp. 131–144, 6 figs., 1919.

[2] Berry, Edward W., U. S. Geol. Survey Prof. Paper 92 (in press).

history tectonic activity was so slight as to be negligible; no mountain ranges were formed, and the strata deposited were almost undisturbed. Whether the alternating inundations and emergences of these low-lying coastal lands were due to changes in the level of the land or to changes in the level of the sea, these changes were relatively slight as compared with those that occurred, for example, in the western United States or in southern Europe, two regions whose paleobotanic history has been fairly well worked out. The record of the evolution of the successive floras in southeastern North America was, therefore, not complicated by such a diversity of conditions, as it was in the uplifting Rocky Mountains or in the mountainous areas of central and southern Europe, and it is consequently more easily deciphered and more readily applied to the interpretation of geologic history.

With the drawing to a close of lower Eocene times in southeastern North America, an event that happened several millions of years ago, most or all of the area of our tier of Gulf states gradually became emerged from the waters of the lower Eocene sea that had covered them. The process was a slow one, the land became fully inhabited and densely forested. Had we been present we would not have known that these momentous changes were in progress. These long intervals of emergence are the lost chapters of earth history. Nature's sedimentary records of such times are largely stored beyond the reach of humanity, and we can only infer their duration from the observed changes in life when once again we can pick up the record that remains in those parts of the earth's crust where this record can be observed.

The middle Eocene in this region is called the Claiborne from a small settlement of that name on Alabama River, where Eocene deposits were in 1833 for the first time recognized in North America. Claiborne time is inaugurated for us with the sediments laid down by a readvance of the waters of the Mississippi Gulf or the middle Eocene Gulf of Mexico over this region. These were deposited on the worn surface of sands and clays of the lower Eocene, and, as we find them to-day in Alabama and Mississippi, consist of aluminous sandstones and siliceous claystones, in general sparingly fossiliferous, but in places glauconitic or calcareous and with fossils. This is the Tallahatta buhrstone of the geologists, so named from the old English name for such a cellular hard rock adapted for use as mill stones. West of the Mississippi River these initial Claiborne deposits are reddish sands more or less gypsiferous, colored and consolidated by iron oxide, which may be an altered greensand, and containing beds of clay and lignite. This is the Mount Selman formation of the Texas geologists.

With the advance of the sea inland the character of the sediments changes somewhat and becomes calcareous clayey sands or sandy clays, usually containing large numbers of mostly marine fossils. These are termed the Lisbon formation from the landing of that name on Alabama River. Still higher in the section is a thin deposit of no great extent of highly fossiliferous greensand which geologists call the Gosport formation, taking the name from another nearby river landing. The Gosport forms the uppermost division of the Claiborne group and in its topmost layers at Claiborne landing it contains a lens of estuary clay packed with the remains of the foliage of the trees that grew in the vicinity at the close of Claiborne time when the Claiborne sea was withdrawing to the southward.

This Alabama succession of Tallahatta, Lisbon and Gosport formations is usually considered as the typical one for the middle Eocene of North America. As might be expected, when these formations are traced for long distances they lose their identity. West of the Mississippi River in Louisiana but two formations have been recognized. These are an older known as the St. Maurice and an upper one known as the Yegua—the latter containing many old swamp deposits and fossil plants, and indicating that at the time the Lisbon and Gosport formations were being deposited in the sea in the area east of the present Mississippi River, the region of northwestern Mississippi, southeastern Arkansas, northern Louisiana and adjacent areas in Texas was a low land surface with a luxuriant vegetation and many swamps.

What might be called the standard Texas section consists of the Mount Selman formation, already mentioned, overlain by a series of yellow sands and clays with lenses of calcareous fossiliferous greensand, known as the Cook Mountain formation, which in turn was overlain by the Yegua formation already mentioned, and which continued to accumulate on the coastal lands of Texas while the lower Jackson sea advanced up the Mississippi Valley almost to the mouth of the Ohio, spread northward over eastern North Carolina, and inland over the whole Coastal Plain of Georgia. Except across Texas, where the Jackson deposits were largely sands and clays laid down along the shores, with occasional slight incursions of the sea bringing in a few marine forms, such as oyster beds, the sediments of Jackson time are prevailingly calcareous and often rather pure limestones. This is especially true in Mississippi, Alabama, Georgia and Florida. Toward the head of the Mississippi Gulf in northeastern Arkansas and western Tennessee where the marine waters were shallowest and where river-borne sediments were dominant, sands and muds eventually smothered the oyster beds and,

after lower Jackson time, the sediments were laid down in swamps or by streams on the land.

The layman is not especially interested in the unfamiliar swarming life of these middle and upper Eocene seas. Of the hundreds of fossil shells that to-day represent this life of long ago about the only familiar forms are the oyster, scallop and cockle. There were many corals, especially during the Jackson, and many representatives of warmer water conditions than obtain to-day in corresponding latitudes. Jackson time introduces other and strange elements into the life of these long-vanished seas. The most striking of these was the ancestral toothed whales or Zeuglodons, which must have been present in great numbers, for we find their teeth and bones all the way from North Carolina and Florida to Louisiana and Arkansas along the line of this ancient sea coast.

These primitive whales appear to have originated from semi-amphibious land mammals in the early Eocene in northern Africa at a time when seas similar to the Mississippi gulf covered the Libyan desert. From thence they spread rapidly to Europe and North America and even to southern South America and Australia. The Zeuglodons of the ancient Gulf of Mexico were quite unlike modern whales, being 50–70 feet long, more than half of which was tail, and at their largest girth not more than 6–8 feet in diameter. The head was relatively small with a tapering snout provided with numerous conical grasping teeth and back of these large cutting teeth with two roots, giving them a yoke-like appearance which is the origin of the term Zeuglodon. Their fore limbs were paddles and their hind limbs had already become vestigial and did not protrude through the skin. They were evidently good swimmers and divers, and their bones were widely scattered over the soft bottoms of the Jackson sea.

Associated with these Zeuglodon bones of several species are the teeth of several species of sharks, and the bones of a marine snake. Except for a fresh water turtle no remains of the animals of the land have been found in the Jackson and this is a great misfortune, for a marvelous mammalian fauna has been found in the basin deposits of this age known as the Bridger and Uinta in Wyoming and Utah. This embraces horses, tapirs, rhinoceroses, camels, titanotheres, along with their attendant carnivores, giant pigs and insectivores, and some at least of these types must have inhabited the well-wooded country that bordered the Jackson sea, but their bones have hitherto evaded the collector.

Our vistas of these shores and the earlier border lands of Claiborne time are hence restricted to landscapes alive with vegetation of strange and interesting types but with animals other than in-

sects unknown.[3] It would be interesting to picture amphibious rhinoceroses and giant pigs in the shallow bayous, and tapirs in the swamps, but we can not be sure of their existence here until their bones are actually found.

The shores were low and for the most part heavily wooded, and the climate was warm and humid, warmer than in lower Eocene times, and plenty warm enough for crocodiles none of which, however, have been discovered in the Claiborne or Jackson deposits, although they were present in this region during the lower Eocene.

The middle Eocene or Claiborne flora that lined the Mississippi Gulf represents but few survivors from the lower Eocene—only 9 or 10 out of over 400 species. Some of the Claiborne plants were the modified descendants of lower Eocene native species, but a good many appear to represent immigrants from Equatorial America which spread northward with the warming of the climate. These came by land, over the waves by means of drift seeds propelled by ocean currents, or in the stomachs of birds.

A remarkable drift seed is that of a form of Carapa, a member of the mangrove association, the seeds of which are a familiar element in the Oriental sea drift. Another striking element of both the Claiborne and Jackson floras was a large species of gregarious fern belonging to the genus Acrostichum, whose modern representative flourishes in tidal swamps in the Tropics. Four other ferns are known from the Claiborne as well as cannas and 6 different palms. There were figs and sea grapes, many leguminous plants, soapberries, alligator pears, ironwoods, cinnamons, gums and persimmons. One of the most interesting Claiborne fossils is the large seeds of a plant closely related to the existing Sapote of tropical America, growing in those far-off days in northern Mississippi.

Another interesting Claiborne plant is the one shown in the accompanying illustration and belonging to the genus Copaifera. It is represented in the Yegua formation by the compressed, large single-seeded pods (Fig. 1). The modern forms number about 16 species of trees—four in tropical Africa and the balance in America, where they range from the Antilles to the Amazon basin. They yield the commercial gum or balsam known as Copaiba gum and have unarmed branches and even-pinnate leaves of a few small leaflets. This Claiborne form is the only one known from North America. Another very common Claiborne plant belonging to the same tribe as the orange, lemon and grapefruit is that shown in Fig. 2 and referred to an extinct genus known as Citrophyllum. It had large well-marked leaves with conspicuously winged leafstalks like a modern lemon.

[3] Dragon flies and ants have been found in the Jackson.

FIG. 1. THE CLAIBORNE COPAIBA GUM
Copaifera yeguana Berry, natural size, based on the existing *Copaifera langsdorfii* Desf., of Brazil.

FIG. 2. THE CLAIBORNE REPRESENTATIVE OF THE ORANGE TRIBE
Citrophyllum eocenicum Berry, 4/7 natural size.

The upper Eocene or Jackson is much richer in fossil plants than the middle Eocene. One of the most interesting localities is in the lower Jackson, where the sea spread far inland over Georgia. At this place, some few miles west of Augusta, there was a shallow tidal estuary lined with mangrove swamps forming an upper Eocene picture like that to be seen to-day around the shores of Miami, Florida, which latter locality marks the northern limit of

FIG. 3. THE JACKSON SABAL-LIKE PALM
Sabalites vicksburgensis Berry, about 1/50 natural size.

the modern mangrove. These curious plants with their prop-like stilt roots live in dense array on tidal mudbanks and have developed a curious resistance to salt water, flourishing in such situations as

FIG. 4. THE JACKSON DATE PALM
Phoenicites occidentalis Berry, about 1/80 natural size.

Panama Bay, where the tremendous tides almost submerge them twice a day. The fruits sprout on the trees and when they have reached a considerable size drop into the water and are carried about by ocean currents until they strike root in shallow water and start a new colony. They are great land builders and are found in the estuaries of all tropical coasts.

Both fan and feather palms were a familiar element along the Jackson coasts where they are now represented by the petrified stems and fruits as well as the leaves, representing eight different species. One of the most common of these is a beautiful species of Thrinax much like the existing Thatch palms of the Antilles. Another and larger fan palm was much like our modern cabbage palmetto, and a restoration of this Jackson species of Sabalites, as it is called, is shown in the accompanying illustration (Fig. 3).

Perhaps the most spectacular of the palms is represented by leaf fragments and fruits found in Texas which show it to have been closely related to the modern date palm. This striking Jackson plant is shown as restored in Fig. 4. All the modern date palms are confined to the Old World and this Jackson species is the only member of the genus known from the Western Hemisphere. The peculiar seeds which have been found fossil remove any uncertainty as to its relationship. It is the finding of such things as date palms, nutmegs and nipa palms, all of which occur in the Jackson, thousands of miles from their existing haunts, that is one of the never-ending joys of paleontological study.

There are six figs, two sea grapes, a custard apple, 12 leguminous trees, 16 different lauraceous trees, ironwoods, dillys, gums and many other things that would be entire strangers in the existing floras of our Gulf Coast that flourished in that region during Jackson time.

One of these is the so-called tropical cedar (Cedrela) a restored leaf of which is shown in Fig. 5. Cedrela is a genus of trees with about 10 existing species in tropical America, where they are mostly confined to the mainland, although during the Tertiary they extended over the Antilles to the southern United States. They are found in the lower as well as the upper Eocene around the Mississippi Gulf, and represent immigrants from Equatorial America which have since become extinct in the United States as a result of the cooling climate during Miocene times.

Finally, there is presented in the form of the restoration shown in Figure 6 a large fruited persimmon found in the Jackson deposits of Texas, where it is represented by leaves and the enlarged and persistent calyx that subtends the fleshy fruits. The soft fruits soon decay and the contained seeds have not been detected in the

FIG. 5. A LEAF OF THE JACKSON "CEDAR"
Cedrela jacksoniana Berry, about 3/7 natural size.

rocks, but the calyx, indicating a fruit nearly as large as the present day cultivated Japanese persimmons, escaped destruction in this as well as in many other cases, and was preserved as an unmistakable token of the long vanished soft fruits of this Jackson species.

Every one in our middle and south Atlantic states is familiar with our common persimmon and its astringent fruits looking like decayed plums and inseparably associated in the folklore of the South with "possums." Few, however, know that the persimmon belongs to the ebony family and that the latter has nearly 300 existing species almost all of which are confined to the tropical countries of the world, being found on all the continents.

Persimmons are first found at the dawn of the middle Cretaceous and they have a long and interesting geological history—their leaves, petrified fruits, seeds and especially their leathery persistent calices being of frequent occurrence in the Upper Cretaceous and Tertiary rocks of the Northern Hemisphere. We can but marvel at the slight structural changes they exhibit in the vast stretches of time that they have been in existence, in fact one of the outstanding results of paleontological discovery has been the immense antiquity of most organic types, even including man.

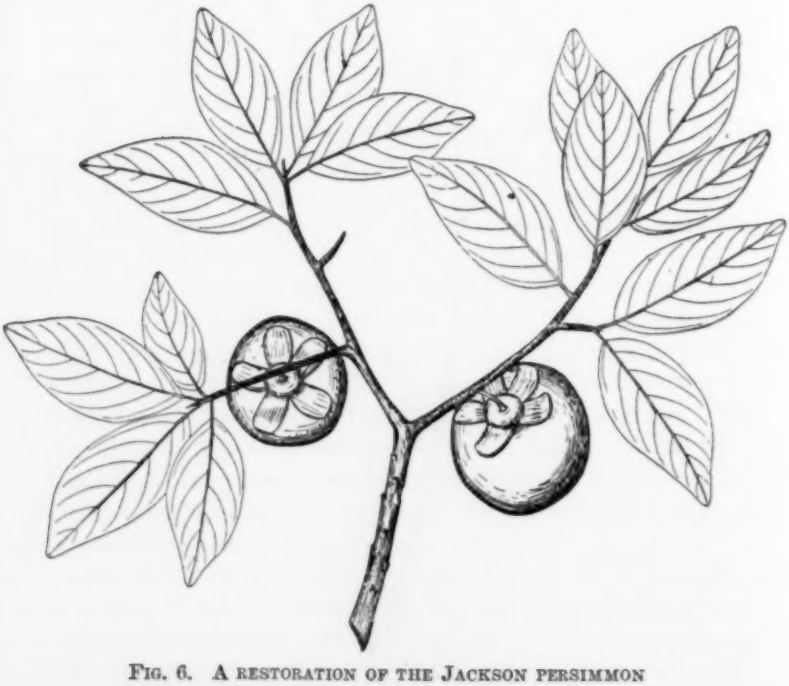

FIG. 6. A RESTORATION OF THE JACKSON PERSIMMON *Diospyros mirifloriana* Berry, about 3/7 natural size.

FIG. 7. MOVEMENTS OF THE STRAND LINE IN WESTERN AND EASTERN GULF AREAS DURING THE MIDDLE AND UPPER EOCENE.

Toward the close of Eocene time the shrinking of the waters of the Mississippi Gulf, already pronounced in the region west of the Mississippi River, became apparent along the eastern shores of the gulf. There is some question whether or not there was any large area that became emerged from the sea at this time, but there was certainly enough of a recession toward the southward of marine conditions to permit the deposition of a series of beach sands, interspersed with swamp deposits, now represented by lignite seams.

Deposits of this sort can be traced for a considerable distance in the state of Mississippi, where they are called the Forest Hill sands,

and where they contain fossil plants that show them to be, partly at least, of Jackson age.

This shallowing and complete withdrawal of the sea from the Texas region, and partial withdrawal east of the Mississippi River, marks the boundary for geologists between the Eocene and Oligocene, the latter epoch being inaugurated from Mississippi on the west to Florida and Georgia on the east by a renewal of typical marine conditions and the deposition of the extensive impure limestones known as the Vicksburg limestone, which extends westward a short distance beyond the river in the state of Louisiana.

I have attempted to give a graphic summary of the middle and upper Eocene history of the Mississippi Gulf in Figure 7, in which the oblique lines represent the forward and backward movement during those times of the coast or strand line. The lapse of time is represented by the interval from the bottom to the top of the diagram. Thus the reader is, in effect, looking at an idealized cross section of the deposits laid down during the middle and upper Eocene in this region, those to the left of the strand line, that is, to the south of it, representing sediments deposited in the sea; and those to the right of the strand line, that is, to the north of it, representing sediments deposited on the land by rivers and lakes, in deltas, by the wind, or the accumulation of organic débris in swamps.

SKIDDING ON THE ROAD TO SCIENCE

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EVERY student of science has doubtless been confronted at times with testimony so indisputable as to give more than reasonable support in formulating a working hypothesis; but I know of no instance pointing to the extreme care that should be exercised in developing a scientific theory than one which recently came within the experience of a fellow-student and myself respecting a subject of Southwestern archeology and ethnology. The story runs in this fashion:

In 1893 an Indian agent for the Pueblo Indians of New Mexico visited Zuñi, where he was given several small terracotta heads typical of thousands that have been unearthed at San Juan Teotihuacan, Mexico, about 1,500 miles away. The heads were said to have been taken from the middle of a large block of adobe that had served as the cornerstone of the old Franciscan church at Zuñi, built about 1692, but which had been broken open during the process of repairing the edifice. The agent frankly admitted that he was not present when the heads were found, but that to the best of his recollection they were given to him by a Presbyterian missionary, resident among the Zuñi Indians at that time. In sending the specimens as a gift to my friend and confrère in 1914, the agent wrote that the large adobe block had been made hollow and the objects placed therein in a rough box or receptacle which had practically disappeared through decay. In addition to the heads there were other Indian objects, such as arrowheads and small, rude stone hatchets. The missionary, according to the story, kept some of the heads and brought the others to the agent in the belief that he might be able to give her some information as to their origin. The agent also expressed the belief that the heads would never have been brought to light had it not been that the block of adobe in which they were found was so large that it was broken to pieces in order that it might be hauled away.

So much for the agent's account, which bears the stamp of verisimilitude except in a couple of minor particulars, namely: It is hardly likely that any one would ask an Indian agent for information respecting things Indian; and we are left to surmise why a few pagan articles were found in the wall of a church, to the neglect of those sacred accompaniments that one would expect to

find in the cornerstone of a Christian edifice. Yet it does not require a great stretch of imagination to assume that the Franciscans exercised that liberal spirit toward the Indians which won their friendship and their aid, especially in the erection of their churches and monasteries; therefore, it seemed not beyond the bounds of reason to believe that the early Spanish missionaries were prompted to offer concessions to the natives, even to the extent suggested; whereas the absence of Christian articles might be accounted for either by decay or because the Indian agent, not having been present, was not informed of them.

In any event, this fly in the ointment will perhaps seem to the layman of minor importance by comparison with the occurrence, at all, of Mexican objects in a New Mexican pueblo so far from their place of origin. Yet, Indian artifacts traveled vast distances. Catlinite found its way through channels of trade from the present Pipestone County, Minnesota, to tribes living hundreds of miles away; obsidian from the Rocky Mountain region has been discovered in Ohio mounds; turquois, evidently from New Mexico, has been found in Mississippi diggings; objects of copper from the region of the Great Lakes have been unearthed from sites of Indian settlements in the southeastern states, and Pacific coast shells occasion no surprise when recovered in the course of excavation of ancient Pueblo villages in the arid region of our southwest, hundreds of miles from the source of supply; while conchs from the Gulf of Mexico are often encountered among archeological remains far inland, not to mention dentalium-shells which found their way from Pacific shores to the Arikara of North Dakota, who also received plant products by trade from southern Arizona and New Mexico.

But we have more direct evidence of contact between Zuñi and Indians of the Valley of Mexico, which might not unreasonably have accounted for the presence of Mexican artifacts so far from home as the cornerstone of a Zuñi church.

If we go back to the year 1542, we will find that when Francisco Vasquez Coronado reached the Zuñi pueblos with his army on the return journey to Mexico, he "rested before starting across the wilderness, because this was the last of the settlements in that country. The whole country was left well disposed and at peace, *and several of our Indian allies remained there.*" Forty-one years later, Antonio de Espejo reached Zuñi from the Rio Grande, where he found crosses erected, "and here we found three Christian Indians, who said their names were Andrés of Cuyuacan, Gaspar of Mexico, and Anton of Guadalajara, and stated that they had come with the said Governor Francisco Vasquez [Coronado]. We

instructed them again in the Mexican tongue, which they had almost forgotten."

This testimony is sufficient to show that there had been contact between Zuñi and Indians of Mexico in the earliest historical period, and further communication was had when the Spanish explorers who followed Coronado and Espejo in the sixteenth and seventeenth centuries wended their way, with Indian companions, from the Valley of Mexico to the far-off Pueblo country in the north. Indeed, there is positive evidence that a considerable body of the earliest New Mexico colonists was composed of Tlascalan or other Mexican Indians who were established in a ward of Santa Fe known as Analco, and that San Miguel Chapel, still in use, was erected for them.

If further evidence of the contact were needed, it might be added that during the progress of excavation by the Museum of the American Indian, Heye Foundation, of the ruined Zuñi pueblo of Hawikuh, with its church and monastery, there were recovered various objects introduced from Mexico, most of them of European origin and of the mission period of 1629-1670; but copper bells of Mexican Indian manufacture and an earthenware pot-cover, painted in typically Mexican Indian designs, have also been found.

So much for theory, which thus far seems to be sufficiently well substantiated to warrant belief in the finding of the terracotta heads in the Zuñi church.

But fortunately the writer knew the missionary, whose name the Indian agent could not recall, as a lady who reestablished the Presbyterian mission and school at Zuñi in the autumn of 1888, spending many years there. And, even more fortunately, she is still a resident of New Mexico, and possessed of an excellent memory even after a lapse of 31 years. The result of a letter of inquiry shed such light on the reputed finds as to dissipate completely the story of the agent as well as the theory built on his statement, which we do not question was made in the utmost good faith.

The cause of all the contention is due to a reprobate relation of Pálowahtiwa, the brother, by adoption, of the late Frank Hamilton Cushing, who, as an ethnologist of the Smithsonian Institution, spent nearly five years at Zuñi, from 1879 to 1884. When Cushing finally left Zuñi during the operations of the Hemenway Archeological Expedition in 1888, it was with the expectation of returning; but the opportunity never came, and his belongings remained in the home he had built, only to be looted long afterward by the native of whom mention has been made.

This Indian one day brought to the Presbyterian missionary, for sale, a box of little terracotta heads which he claimed to have

found in an ancient ruin near the farming village of Ojo Caliente, which corresponds in locality with the ancient Hawikuh. Knowing of the existence of this ruin, and fully believing the Indian's plausible yarn, the missionary purchased the lot of objects, and believes that others may have been given or sold to the agent; but never to her knowledge has the cornerstone of the church been disturbed.

Wishing to have an expression of expert opinion of the "find," the missionary took most of the specimens to the Smithsonian Institution at Washington in 1893, when she went east to attend the World's Exposition in Chicago. Here she met Cushing, to whom she gave an account of how, when, and where she had procured the heads, and who recalled that they had been given to him "by a visiting professor," whom I surmise to have been the late Adolf F. Bandelier. The visitor had obtained the objects in Mexico, and on his way home had stopped at Zuñi and left them with his host. The missionary, now learning of their true ownership for the first time, left the little collection with Cushing, expressing her regret that it was not possible to return also the rest of his belongings which she feared were being disposed of in the same manner. Indeed, during the following autumn the family of the man who had sold the little heads to the missionary offered other articles which evidently belonged to Cushing, which she, of course, refused to purchase.

During the ensuing winter or in the following spring, the Indian agent visited Zuñi, and on "displaying formidable weapons" the Indians thought it discreet to evade a charge of theft by placing in the agent's hands the rest of the plunder, thereby unconsciously lighting the fuse that, after more than thirty years, has resulted in the explosion of a very pretty theory, built on the most plausible testimony, respecting the origin of the terracotta heads.

All of which goes to show how easy it is for the student to skid on the road to science, even after using every care.

THE NEED OF AN INTERNATIONAL MIND

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WAS it H. G. Wells who insisted upon the fact that the political boundaries of Europe are still essentially those which belong to the horse age of transportation whereas we are now living in an age of travel by means of the locomotive, the automobile and the airplane? It is now so obvious that people separated by a hundred miles of space are in fact much nearer together than they were even fifty years ago that one would not insist upon the point were it not for the pregnant corollary which follows from the fact. The progress of invention has greatly narrowed the effective size of the earth as a home for man. The various peoples of the earth are physically much closer together than heretofore. There is an intimate interweaving of their interests. What affects one now reacts upon another more intimately than our fathers could have anticipated even a generation ago. Notwithstanding the separations and antagonisms among the parts of this general human society the whole has become more organically connected than ever before. All mankind is tied together physically in a way which no one a hundred years ago could have considered possible. All this is a commonplace of current thought.

But we are not united intellectually. The progress of invention has brought us together physically. But we have failed to make a corresponding and sufficient advance intellectually; and we have particularly failed to do so spiritually. In an earlier time there was a certain unity of intellectual life in Europe centered about the church and the Bible. The great Hebrew literature contained in the latter furnished a significant and common part of the culture of the time and held peoples together by the bond of a common intellectual and spiritual possession. H. G. Wells has urged the desirability of creating a new Bible of civilization to give to the modern world a like common intellectual and spiritual possession. Whatever might be the value of such a common modern Bible of civilization, if it were formed, we can not say; it is clear that there is no prospect of the immediate construction of one.

But there is an important thought which may be symbolized for us by the imagined existence of such a work. Let us think for a moment what its value might be. If such a compact and comprehensive Bible of civilization were universally distributed and if

its materials were so selected as to be received with confidence everywhere, it would give to all men a certain common intellectual and spiritual possession, a certain common ground on which their association could be built, a certain common starting-point from which their thought could proceed, and consequently a certain commensurability in the conclusions reached which would go far toward making it possible for them to understand each other better than they do at present. Such a work would do much to remove the uncalled-for differences which separate peoples and needlessly set them against each other. It would give them a common interest of an intimate sort.

But there is certainly no prospect of an immediate realization of such benefits through the construction of a universal Bible of civilization.

These considerations leave us face to face with an important question, the answer to which they do not help us to attain. What shall we do to lead to the development of an international mind, a common view of truth and humankind, such as will contribute best to the progress of an enduring civilization based on the nobler qualities of man? What should be the starting-point from which we may proceed to realize the goods which we are considering? This is a question which has been asked by many people. Where shall we turn for an answer to it?

In the present disturbed condition of the world the question is more insistent than ever and it clamors still more loudly for an answer. The immediate and permanent international reality finds expression in the economic sphere, in forms of international workmen's associations, in finance and commerce and even in the less obtrusive internationalism of science and religion and art. Varied national interests are involved in the problem and they often clash with one another. But there is one place where the current nationalisms need not interfere with the development of an international mind. This is in the domain of pure thought where the endeavor is made to reach a systematic and synthetic order of truth and to afford a general view of the world of human thought within the limits of a rigorous scientific knowledge. It is inevitable that we shall think of this as the place in human thought at which it will be most profitable to labor toward the formation of an international mind, because it is here that success is most likely.

Even when we turn to the domain of science, where thought is more exact than elsewhere, we find difficulties in the way of an intellectual synthesis. Contemporary intellectual life is not unilateral in any of its domains. Science at present is many-sided. Its diversities increase. New chapters are being added to all the

sciences. The difficulties of an integral view are increasing; and the need for achieving it is growing at the same time. Success can not be expected except through organized and careful effort; and such labor will need an organ and a clearing-house for ideas. The work can be done successfully in no other way. There must be a broad and open forum for the analysis of interesting and debated questions by those best qualified to treat them.

Fortunately, *Scientia*, the international review of scientific synthesis published at Milan, Italy, offers just such a forum for discussions which contribute to the philosophic synthesizing of science and the intellectual fraternization of peoples as is needed at the present time. One principal purpose for the writing of the present article is to assist in promoting those ideals for which *Scientia* stands, and to further in some measure the inspiring program which the editors of that unique journal have formulated.[1] Its world-wide distribution has exceeded the expectations of the editors and has encouraged them to promote a campaign for its larger distribution and for the wider diffusion of the spirit which animates it. The entire contents are accessible to those who read French, since the articles of those who write in other languages are printed in French as well as in the language of the author.[2]

The ideal set by the editors of this journal for promoting the philosophic synthesis of scientific truth and the development of a common international basis for philosophic interpretation is of such character as to merit the attention of all those who are concerned with the broader aspects of the development of scientific thought. The character of this ideal may be seen from an example of the editors' practice. Let us notice the nature of the demands which they are making upon authors who have been asked to contribute to an international symposium upon the theory of relativity. (Perhaps I may give a brief account of this without laying myself open to the charge of divulging what should be kept private.)

The present state of the theory of relativity, the degree of maturity which it has reached, the extensive and varied development of it which has been set forth in so large a literature, the doubts and difficulties which it has encountered, the enthusiasms which it has engendered, the difficult form which much of the exposition of it has taken, its intimate relations with the deepest realities accessible to investigation—all these render desirable a coordinated international inquiry into the theory. The inquiry which the edi-

[1] American subscribers can conveniently purchase *Scientia* through Messrs. Williams & Wilkins, Mount Royal and Guilford Avenues, Baltimore, Maryland, at ten dollars per year (twelve issues).

[2] Among recent contributors are the following Americans: W. D. MacMillan, S. Nearing, L. E. Dickson, W. S. Adams.

tors propose has at the same time the following two fundamental purposes: (a) to submit the theory to a careful and profound objective examination in order to bring to light its points of weakness and to suggest the revisions necessary to remove these objections; (b) to perform a work of clarification by seeking to render either the theory in its entirety or in one or another of its fundamental points or else the principles which constitute its foundations or the results to which it leads, by seeking to render these accessible to all learned persons with a philosophic tendency and in particular to those who are not mathematicians.

With these aims in mind the contributors are to choose their subjects and to adopt methods of exposition which permit the development of the thought without recourse to technical mathematical ideas or mathematical formulae. It is, then, necessary for the author to express himself solely in ordinary language and in a manner which is accessible and clear to those who are attracted to the theory and yet are without the technical equipment by means of which the investigator carries on his work. By this means the contributors are to lead the reader through to the fundamental conceptions of the theory and to an understanding of its physical significance.

It is thus seen that the ideal of scientific synthesis which *Scientia* seeks to realize demands that the broader conceptions of scientific thought shall be made accessible to all cultivated persons with a tendency to philosophic interpretation. The work to be achieved is greatly needed. It must contribute effectively to the formation of an international mind. It deals with that part of our intellectual life in which there is most hope for some uniformity of philosophic interpretation, namely, that part which has to do with science. The diversity of individuality will remain, as it should; but the active association of minds devoted to a philosophic synthesis of science will do much to create in this field the common atmosphere and common foundation which are essential to a broad conception of the import and meaning of nature and natural forces.

Those who feel the need of a common meeting ground for the thinkers of different countries and for the workers in different fields perhaps do not at present constitute a large host, but they form a mighty company on whom much of the further progress of truth depends. The more profound wisdom of mankind must not be parceled out by national boundaries nor by barriers which separate one portion of thought from another. Science is now cultivated with the greatest success and earnestness, both in its principles and in its applications, without any direct reference or adaptation to philosophical or religious interpretation, and it makes its way freely

through every part of the earth and the sky and penetrates to the substances below the surface and into the depths of the sea. Every unexplored region attracts the intellectual traveler with the fascination of the unknown and leads him to spare neither peril nor sacrifice if these may aid him in throwing light into what might otherwise involve a scientific mystery. This disinterested and depersonalized investigation must proceed unabated and every dark corner must be searched for its hidden truth.

The partial knowledge which is gathered in this way by various workers through all countries and in all divisions of scientific inquiry should in some way be brought to the focus of philosophic interpretation and synthesized into an organic unity whose power may be felt in the spiritual life of mankind. Here is a work which will require the pooling of all our intellectual and spiritual resources. In some way or other the partial views of things must be united into a whole. We need a philosophy which seeks to know the very essence of science, an astronomy which goes forth to discover the eternal mysteries of infinite space, a physics and chemistry which reveal the secret of the infinitely small atom by means of the dispersive power of the intellect, and a psychobiology which can lift the veil from the mystery of life and spirit; but above all we need that synthetic view of nature and man which contemplates them in their entirety and understands a little of the meaning of the universe. As a first step toward this we require a broad synthesis of scientific truth along philosophic lines.

The devotion of a few thinkers everywhere to the achievement of this high ideal will do much toward the development of the international mind which seems to us to be so much needed at the present time. Among the separate sciences of the more exact sort there is and has been for some time a large measure of agreement which is not hindered by international boundaries; but it seems that no great success has yet been achieved toward the uniting of these partial international minds into a more comprehensive one which shall embrace all the more profound concerns of our humankind. It is on the importance of the latter that we place our present emphasis.

The task is difficult, but the difficulty does not seem to be too great for success. It is perhaps necessary to begin at the right place. Certain intellectual activities are individual in their character or belong at most to a restricted group of people. This is the more true as they pertain more to the meaning and significance either of things or of thoughts. But in a range of thought where there is so much agreement among thinkers as to the facts and the principal laws as there is in the natural and mathematical sciences,

it seems that an understanding of meaning and significance could be so clearly conceived that there would be a fair agreement on some of the matters of most profound philosophic import. That there is great difficulty in attaining such a measure of clarity and such a comprehension of the meaning of things must have been apparent to every thinker in our age who has discussed these problems intimately with a group of thinkers representing the several sciences and thus moved by the varying traditions which animate or restrict the attention of workers in the different fields. But success should not be impossible. It is a matter of great human value and fraught with large possibilities for the development of science itself. It is a work to inspire the best efforts of the greater intellects.

Among the publications which at present foster such work and further such interests *Scientia* appears to me to hold a unique place. Contributions to the same purpose are made by other periodicals and the cause is advanced by a number of individual thinkers. But this ideal and this goal seem to be in the forefront of attention with the editors of *Scientia* and they are making a contribution toward an international cooperation in scientific work which deserves the hearty support of every one who believes in their inspiring program of the philosophic synthesis of science and the intellectual fraternization of peoples.

FOUR GENERATIONS OF MEMORABLE BOTANISTS

By Professor **WILLIAM TRELEASE**
UNIVERSITY OF ILLINOIS

ONE midsummer evening last year, as I sat on the terrace before Madame Augustin de Candolle's residence overlooking the beautiful estate of Le Vallon, where France and Switzerland meet along the lower stretches of the picturesque Arve, it occurred to me that no American journal had brought to my notice the passing almost simultaneously of two of the four generations of botanists whose distinguished name our hostess bears. Augustin de Candolle died on the ninth of May, 1920. Only a few months earlier, he had written to express his appreciation of a note of sympathy addressed to his mother after the passing of his father, Casimir de Candolle, on the third of October, 1918, a note that arrived only after her own eyes had closed for the last time.

As Madame de Candolle told me of the consolation that her husband found during his own last stricken days in rereading the halting lines that affection and veneration had dictated in reply to his letter, I recalled that a quarter of a century earlier Casimir de Candolle in his characteristic quiet and polite but positive manner had turned to me, while we were dining, with the astonishing statement, "You knew my father." No protestation that the acquaintance was only that of a neophyte asking the aid of a master could mask the fact that the response of the master was an exemplification of the kindly helpfulness shown by four generations to whom scientific assets, easy circumstances and rare learning crystallized into its unusual concomitant—wisdom, carried the obligation of personal helpfulness as well as of professional productiveness.

This spirit was exemplified when I last saw Casimir and Augustin together, while the war-cloud was gathering, critically approving purchases from a list of new books; for the family policy of two preceding generations was continued, that no book of real botanical value should be sought in vain in the Candollean library.

It was shown in quite a different way, when, after enjoying months of hospitality such as no endowed institution could surpass and few equal either in spirit or resources, I said good-bye forever to Casimir de Candolle as he handed the last of my manuscript cases into a cab at the Molard, to which he had insisted on accompanying me through a December rain from the ancestral home in the Cour de Saint Pierre on top of the overhanging hill.

Quite unexpectedly my own later studies have been directed along lines earlier mapped, and well mapped, by the first three of these four generations of Swiss botanists, each of whom left his work complete for its day: the mistletoes, oaks and peppers. The Candollean herbarium, therefore, has become a shrine of what is classic for all future students of these groups. It contains in compact form the chief materials—of which these are a small part—to which one of the world's greatest publications, the Prodromus Systematis Naturalis Regni Vegetabilis, perpetually refers for verification of facts imperfectly expressed in even the most precise and methodically chosen words. Though my interest had not then touched his own specialty, Casimir de Candolle was a helpful guide as I reviewed those of his father and grandfather.

Geneva is justly proud of the achievements and the personality of its citizens. For centuries it has been the refuge of those whose thought revolted against being unduly curbed. A decade ago, the bastions of its abandoned fortifications were consecrated to relief portraits of the great leaders of religious reformation. The brow of its hill along the river is surmounted by the cathedral of Saint Pierre, beside which stands Knox's humble chapel.

It was on the square fronting these churches that the father of Augustin-Pyramus de Candolle established the home that the latter devoted in large part to the accommodation of library and herbarium, and that for two generations now has been turned over entirely to these material equipments of a scientific impulse which has led to self-imposed industry such as money rarely buys. Here almost up to the day of his death Casimir de Candolle was to be found, pleasurably if almost hopelessly trying to bring the chosen work of a lifetime to conclusion; just as his father and his grandfather had striven to produce that great desideratum of all time, a Flora of the world—to be complete for its day and generation.

The de Candolle family is originally a French family. In the seventeenth century it had fled from the restraints of Provence to the religious freedom of Geneva. Still, it would be wrong to say that the botanists of this family are other than French Swiss, with whatever that expression may imply, for it was more than a century later that the initial of the four generations of botanists who have made it famous was born.

These men were not narrow-minded specialists, trained and educated within narrow bounds. Each, in his day, was a liberally educated public-spirited citizen of the city and the canton. They naturally differed in manifestation of the fundamentals of good citizenship, each responding to the times in which he lived; but one love of nature and of science, which is its organized method and expression, was transmitted from father to son.

If this has proved less appealing to the latest generation, the fact is easily understood in view of the more sedentary less materially constructive phase into which botany seems gradually to be passing, and of the increasing lure of constructive world activities.

Of Casimir de Candolle's sons, the elder, General Raymond de Candolle, of the British Army, an eminent engineer, with a distinguished record as a great railroad builder before his participation in the World War, seems not to have cared to follow in the scientific footsteps of his father and grandfather; and the younger, Augustin, found active legal and diplomatic activities almost if not quite a balance for the quieter and more withdrawn activities in which his ancestors so delighted, but to which he returned at the end.

That Augustin's sons, developing young men of charming personality and brilliant mentality, do not appear to be at all drawn to lives of botanical activity must be admitted with recognition of the remarkable fact that the priceless family treasure of library and herbarium have been entrusted by them and their family to the keeping of the city of Geneva, where, at the botanical garden on the shores of the beautiful lake, facing the Alps with Mont Blanc towering in the distance, they perpetuate the Candollean tradition that they belong not to individuals but to the scientific world, for which four generations of investigators have labored assiduously in varied fields of botany.

Except for the newer biologic studies comprised in a general way under the name ecology, no botanist progresses far in any branch of botany without encountering the name de Candolle in connection with its fundamentals, whether his interest be in morphology, physiology, mycology, monographic descriptions, the geographic distribution of plants, or their classification along lines of true relationship, once called a natural system and now called a phylogenetic system.

Augustin-Pyramus de Candolle
(1778-1841)

Augustin-Pyramus de Candolle, the founder of the Swiss line and of its chain of botanists, is claimed by Sachs as French. This seems hardly accurate, for he was born in Geneva and was twenty years old and well grounded in the humanities when, his canton becoming politically French, he began his active life as a student of medicine and an original worker in botany at Paris.

The road to productivity in science was then less than to-day what his native language so expressively calls "le chemin des écoliers." When he was only twenty-one years old he began, and

AUGUSTIN-PYRAMUS DE CANDOLLE

completed in five years, the publication of the finest treatise yet produced on succulent plants. At twenty-six he had written on the medicinal properties of plants and had started a Flora of France. At twenty-eight he discovered the modifiable rhythmic periodicity of the "sleep" of plants. He lectured on the field of what had become his passion in the Collège de France, and his breadth of interest and talent were such and so fully recognized that for a half dozen years he served as a government explorer in botany and agriculture between the North Sea and the Mediterranean.

If the Napoleonic fortunes had not changed, it is quite possible that he might have remained bodily, as he was ancestrally, French, and that Geneva's loss might have proved the lasting gain of the mother country through the addition of his distinguished life and line to the many of which Paris is justly proud. But it was not so ordained. A chair of botany was established for him in the city of his birth, and from early mid-age until his death, at the age of sixty-three, he was again a Genevese; laying fascinatingly the foundation of a general morphology of plants; exemplifying their natural classification in a botanical garden and expounding its principles; initiating the proposed summary of the known flora of the world, modestly and understandingly called a Prodromus; and bringing together the great herbarium and library which he bequeathed to his son Alphonse with the tradition that they were public rather than private collections and that they and the Prodromus were to continue to grow.

From bust and medallion one judges that Augustin-Pyramus de Candolle was a large man, strong-featured, full of energy, decisive. In his engraved portrait, one sees the thoughtful, learned scholar. Both impressions seem to be grounded in his life as a constructive citizen and a producer and path-finder in his chosen field of scientific activity.

Alphonse de Candolle
(1806-1893)

Alphonse de Candolle (Alphonse-Louis-Pierre-Pyramus), unlike his father, inherited a trust for science. On a generous education he built a botanical career paralleling that of his father. Born in Paris, but a Genevese from his eighth year until his death, except for a distinguished preliminary legal practice he collaborated with his father on the Prodromus until forced to carry it on at first alone and then with his son Casimir as coadjutor. Alphonse de Candolle's interests were unusually broad. In his turn he did talented monographic work, but this did not hold his hand from physiological experimentation of a high order, and he sketched unusually well the

ALPHONSE DE CANDOLLE

principles of plant geography and was well acquainted with paleobotany.

If, perhaps, less in the ordinary public eye than his father, Alphonse de Candolle was a force in the community and equally known and equally appreciated by all those to whom the amiable science was at once vocation and avocation. In his turn he held the professorship established for his father. His first publication, at the age of eighteen, was on a fungus. His broader tastes had declared themselves before he was thirty years old. His ethnobotanical study of the source of origin and the enforced migrations

of cultivated plants still stands as a classic. No more readable or cleaner-cut analysis of phytography and its methods seems likely ever to be made than he presents in "La phytographie, ou l'art de décrire les plantes."

As he had worked at his father's side during the earlier part of his life, so he had for the collaborator of his later years his son Casimir. Together they added to both library and herbarium. Together they carried the Prodromus, begun in 1824, to a point when, after half a century, its completion along the original lines seemed no longer feasible or desirable. Together, they instituted on new lines, five years later, a series of Monographiae Phanerogamarum, in which, as in the Prodromus, cooperative work by others was welcomed.

Alphonse de Candolle sometimes is spoken of as "le magnifique de Candolle." While his repute as a botanist was growing—and his prestige was such that admittance to his scientific circle was equivalent to recognition among the "Who's Who in Botany" of his day—worldly affairs prospered under his wise administration.

As with his father, engraved portrait and bust present to the eye of a stranger different aspects of Alphonse de Candolle, both evidently characteristic of the man. In the one, the steady-going judicial man of affairs and of science is to be seen; in the other shines that alertness which led Asa Gray to say to me once that the intuitive genius of de Candolle was unequaled.

Casimir de Candolle
(1836-1918)

Casimir de Candolle (Anne-Casimir-Pyramus) exemplified remarkably the influence in human life of heredity, education, environment and a sense of duty. Born in Geneva, his affections crossed the channel; his wife, a community worker of rare devotion and energy, was Swiss-English, and his children were born in England, though his residence was in Switzerland. From the first his bent was along the line of science, as his grandfather's had been along that of history and his father's in jurisprudence. Generously trained in mathematics, chemistry and physics, he came on the stage when Naegeli's observations and Sachs' experiments were opening up a line of botanical study well worthy of exploration and still being fruitfully exploited by workers of physico-chemical aptness.

Phyllotaxis, deviation from typical structure, the significance of the anatomy of various members of the plant, the structure and movement of the leaves of Venus' fly trap, the latent life of ungerminated seeds: these and numerous other phases of morphology and physiology are among the things that caught his observant attention and that he elucidated,—always from the proximal physico-

CASIMIR DE CANDOLLE

chemical or mathematical rather than from the ultimate or teleological viewpoint. One might suppose that with his taste and education he would not have escaped the insistence of such problems.

His first publication, at the age of twenty-four, was based on a study of the generation and regeneration of cork that he made while inspecting family properties in the south. As with his father and his grandfather, the Prodromus proved a pivot in his activities, and, exemplifying the nature of such undertaking, one small fragment of its topic absorbed the greater part of his long life. In 1864 he published in a preliminary way on the enormous family Piperaceae, which five years later, when he was only thirty-three years old, he monographed for the Prodromus in its entirety so far as the materials of the day permitted. From the age of twenty-eight until his death at the age of eighty-two, hardly a line, with exception of Peperomia studies by Henschen and Dahlstedt, was published on this great group of tropical plants except from his pen. Since his passing, several regional papers on it, written by him, have been published; a memoir on the morphology of the Piperaceae exists in manuscript; and a key to its many species, to which much of the keen energy of his latest years had been given, fittingly forms the major part of the first volume of a new journal, *Candollea*, dedicated to the illustrious family whose name it bears.

In manner, Casimir de Candolle exemplified perfectly the polished courteous kindly gentleman. He was a man of positive con-

victions; but just as in his scientific work he was given to a deliberate weighing of the facts under his eye and quite uncontroversial as to their teleological bearing, so in his daily relations he saw and did what it was his to do but did not enter into fruitless acrimonious debates. Perhaps the most caustic remark that I ever heard him make was once, when I had expressed surprise at the rapid growth of our big-trees (Sequoia) in Geneva, and he said "Yes, but I sometimes think that they are too frequently planted"—an opinion the weight of which has been growing on me ever since, though I experience a sort of horror whenever I see one of them laid low.

As with the preceding generations, and to a greater degree, bust and portrait are discordant in the case of Casimir de Candolle. The sculptor seems to me to have missed the truest expression of his character—just as in the other cases the plastic art has brought this out; but, though less kindly than was his wont, perhaps, he looked into the camera with the clear-eyed directness that, with kindliness, was his most marked personal trait.

Augustin de Candolle
(1868-1920)

Augustin de Candolle (Richard-Emile-Augustin) was born in England, and his secondary education was English. His predilection was for public service and his training was in the law, with the broad background of general culture lacking to none of his family. Though he did not lose these professional and humanistic interests, he accorded much of his scant fifty years of life to the traditional calling of the family, to which, after his father's death, he fully yielded. Somewhat as the mathematical trend of his father's mind had led to conservatism in certain directions, the judicial training of Augustin, like that of his grandfather, equally led to carefully weighed conclusions.

As his father had done, Augustin felt the appeal of certain morphological and physiological phenomena, and he published on both. His first papers, at the age of twenty-seven, were physiological; but four years later he had begun on methodical descriptive work. Cooperating with his father in publishing the Monographiae, and confronted with the daily demands on library and herbarium, he naturally if not inevitably found in the field of descriptive botany the restful task of such time as his arduous duties as British consul during the period of the war yielded.

That he did not undertake to monograph large families is readily understandable; that he did well the sometimes more difficult work of naming authoritatively material from far lands falling within groups that he had not monographed speaks for the breadth of interest and of talent begotten by his unsurpassed environment.

AUGUSTIN DE CANDOLLE

Not unfittingly he was called on for a period of years to preside over the Société botanique, and over the broader Société de physique et d'histoire naturelle of Geneva.

Less French and more English, perhaps, less a devoted specialist, more a man of the active world, Augustin de Candolle was yet an excellent botanist. To the end of his short life he maintained and exemplified the traditions of a family of botanists unbroken for four generations, who will live far into the future as vital forces in the science to which their lives and fortunes were devoted.

Their memory will be kept green so long as botanists continue to be attracted to Geneva by the municipality's monumental collections of plants,—formed by de Lessert, Moricand, Burnat and Boissier, to which, in fulfilment perhaps of its founder's hope if not injunction of a century ago, the Candollean herbarium and library are now added through the joint generosity of the family who brought them together and the city which stands so well to the fore in the history of religious liberty and scientific advancement.

In the halls of the University of Geneva are busts, which, even though they lack the expressiveness that only the human eye carries and which bronze can not seize, will give pause for many generations to the visitor who tries through such imperfect aids to visualize the personality of these generations of great men who have joined their strength to that of others in making Geneva great among the cities of the world.

THE NEXT SCIENCE

By Professor ARLAND D. WEEKS

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THE place of science is now well established. To the application of scientific knowledge are ascribed increase of wealth, improved health conditions, perfected means of communication and transportation, and a multitude of practical conveniences. The nineteenth century was known as a century of science, and the past two decades have seen still further scientific achievement. From the slight beginnings of realism and science of the later Middle Ages an increasing amount of effort and attention has been given to scientific investigation and with noteworthy results.

It would be a mistake, however, to regard the past century or more as a thoroughly scientific era. Science is but one phenomenon in the total social mind of the present time. Science and barbarism may exist in the same society, as witness Europe of the past decade, even in the same individual. It can not be claimed that science has conquered the modern world. Its achievements are many and conspicuous, but large sections of life appear to lie outside of its jurisdiction as at present described.

It can not be claimed that the spirit and method of science have made a conquest of legislation. Fact finding and scientific impartiality are not yet synonymous with legislation. In international relations the functioning mind appears to be at a stage comparable to that of the mind preceding the scientific era.

The failure to conserve natural wealth and to utilize the potential resources of society is one of the weaknesses of civilization. Water power, coal, forests, structures destroyed by fire, ill health and other items of waste testify to the failure of science to keep the social house in order. Poverty and deprivation exist in modern nations. Unemployment is common. The normal state of modern society seems to be one of abnormality with reference to employment.

How short is the arm of science may be observed in the case of scientific specialization. Consider dyes. Dyes may be regarded merely from a chemical viewpoint. The science of dyes is a well-marked-off field within the large field of the science of chemistry. So far as dyes fall within chemical science these substances are mostly for the coloring of fabrics, but the human significance of dyes transcends the laboratory. The coloring of fabrics plays a

large social rôle. The social bearings of the substances we call dyes are far-reaching and hint at possible science quite outside of the ordinary. But the immediate science of dyes stops with chemical traits. It could not be claimed that society is fully scientific with reference to dyes until it recognizes the social rôle and ultimate consequences of dyes as well as the actual chemistry of dyes.

The same point of view may be taken with reference to almost any substance. The science of explosives is a technical and circumscribed branch of knowledge when confined merely to chemistry. Explosives as a social fact invite to a superscience still rather beyond our age. Indeed, perhaps the times call for superscientists whose vision, not limited to the physical or chemical qualities of materials, shall extend to the human scene in all its fullness—to welfare in the concrete, and of the widest social reference.

A like separation of technical science from human circumstances and considerations is illustrated in the profuse manufacture of unnecessarily fragile and perishable articles of commerce. A large amount of raw material and human labor is wasted through being used in the manufacture of wavy glass, short length bed sheets, acid-distended leather goods and deceptive textiles. To be sure, we set the scientific detector on the trail of the scientific cheat, although often too late.

Are we to depreciate science because of its shortcomings? Impressed with the failure of science to bring the millennium, should we abandon science and return to the former humanistic learning, giving Latin its earlier place and closing the physical laboratory?

The challenge of the times is not to less science but to more. Science has laid the foundation upon which may be erected a body of knowledge as yet merely hinted at in psychology, sociology, economics, ethics and public affairs. With reference to the social and human sciences, we are now about where the medieval schoolmen were when Roger Bacon was languishing in a dungeon for being convicted of chemical experimentation. This is a scientific age—to an extent. It is prevailingly non-scientific. The social, political, financial and international questions to which no answers are at hand would convince the most skeptical that there are fields of potential science relatively undeveloped. We are of the Middle Ages in our point of view regarding social research and experimentation.

Certain obstacles stand in the way of extending science to the social field. The expense of fact-gathering for the new sciences is to be noted. The development of physical science was delayed because of costs. It was easier and cheaper to teach Latin than to present physics, bacteriology or chemistry. The compilation of

scientific knowledge is tedious and expensive. A classical college could be supported for a sum that would scarcely maintain a single department of science in a modern high school. Physical science has always had to struggle against expense and difficulties of procedure. In the case of the projected social and vital sciences, the cost of fact-gathering and of reaching a high degree of probability, of research and experimentation, would no doubt exceed that with which we are familiar in the physical sciences.

Not only is there a financial burden to be assumed in the building up of a comprehensive social science, but there is an antagonism to the free use of hypothesis like that which existed three centuries ago to impede the development of natural science. A large majority of people to-day would feel much the same horror toward research and experimentation touching social questions as was felt by the bulk of population three centuries ago toward new views of nature.

The study of natural and physical science has been successful because for a century methods have been employed that lead to new knowledge. The scientific student or investigator assumes that new knowledge lies ahead; he assumes that the existing state of a science is only a passing stage of development. His course is to work forward on the basis of established positions and to renounce theories and convictions whenever the evidence demands renunciation.

The methods of scientific research conform to the outline laid down by Huxley. Observation, comparison, generalization and verification constitute the main steps of procedure, whether the research is to establish the relation of bumblebees to the production of red clover seed or to arrive at a cure for a disease. Francis Bacon's conception of scientific procedure contemplated an exhaustive and minute observation of natural phenomena prior to hypothesis. Modern science short-cuts the observation by proceeding under ingenious guesses which if successful bring to speedy end a procedure of fact-gathering which by the Baconian method would be hopelessly burdensome.

To equal in the social and civic field the successes of physical and mechanical science of the past few generations will require a transfer to this field of the essential methods of scientific research. Observation, comparison, generalization and verification must be applied with the freedom of research if the final product of social, economic and political science is to bear favorable comparison with the fruits of present scientific investigation.

Utilizing the methods of existing science the new science will supplement and tend to complete the imperfect structure of organ-

ized knowledge. The past century may be regarded as having prepared the foundations for a many-storied building of knowledge, but as having left the building with raw walls scarcely above street level. Natural, physical and mechanical science is but a beginning, for there remain the further application of present science to human welfare and the organizing of distinctly humanistic sciences—forms of knowledge identified with superior forces and behavior.

The spirit of scientific inquiry is not less essential than method. Calmness, patience, teachableness, fairness—these are needful. The true scientist expects to prove all things, to be found in error, to go forward to unforeseen conclusions. Can the new science do otherwise? Rootedness of ideas and proscription of inquiry have no more place in social science than in metallurgy or microbiology. And tentative theories and even bold guesses, valid in medical and in electrical science, have corresponding, though possibly but temporary utility, in formulating the humanistic science of the future.

The new scientist, or superscientist, whose wisdom will include that of making good use of what he knows, will be an adept in working his way among the theories and the convictions of his fellows without being chafed and irritated. The present-day scientist is conscious of variant opinions and is glad to explore these and confer with their advocates. Political and social knowledge having any claim to serious consideration can not be built up by persons who insist upon running only with others of the same opinions. There is, it is true, a satisfaction in the hearing of one's own views rehearsed and in being reinoculated with one's own germs, but this pleasure may be made to give way to the delights of discovery.

I have touched in briefest outline some of the shortcomings of present-day science and indicated the field wherein might be formed a body of scientific knowledge characterized by specific social reference and utility. By no means should we turn in our tracks and go back to the exhausted cultures of the classical past, though science has been disappointing. Nor should we judge the case for science by the modern specialist who is equally zealous when engaged on the chemistry of Christmas candles or the chemistry of colloids and gases for the destruction of future foreign populations. A beginning of science has been made. It remains to press on in the scientific spirit, with purpose to bring within the realm of verification a great territory still given over to credulity, prejudice and fanaticism.

To illustrate the point of division between the old science and the new let us consider John Burroughs. I yield to no one in my

admiration of John Burroughs, but in the limitations of his field of observation there was something that speaks of the times. He was a close observer of the birds, plants and animals in the neighborhood of his Hudson River farm. As a grape grower and a shipper of grapes to the New York market his experiences resembled those of some of his neighbors, who instead of receiving a check in payment for fruit shipped, received, instead, a bill for freight and selling charges. Burroughs finally gave up some of his vineyard. One may read every book that John Burroughs wrote and find that while the biography of Jenny Wren is complete, there is a total absence of scientific curiosity with reference to the grape market.

As great as are the achievements of modern science, still greater achievements are conceivable. It would be grievous error to assume that there is little left for scientific exploration. Some have even argued that materialistic science has made the human race no happier than before, in which event the hope of the future lies with more science, or different, or both.

One can scarcely open a newspaper without chancing upon topics that suggest more than a day's work for the future social scientist. I quote several titles from the November (1923) *Nation's Business*, published by the United States Chamber of Commerce: "It costs too much to sell food," "America may abolish poverty," "The railroads ten years from now," "Remaking the new tariff to fit," "Human nature in business," "Recent federal trade cases," "Can't we carry freight to your doors?" Not one of these topics fails to challenge the investigator. The popular treatment of topics of this class looks in the direction of science, but rarely achieves authority and impartiality. Society has yet to provide staff and resources for genuinely scientific exploration of contemporary social problems and conditions.

The spirit of inquiry which has been a feature of the past century of science has a rich territory in matters that come close to men's business and happiness. Physical science can not resolve the tangle in which the world finds itself; and impulse, reaction and incantations are out of place. The Newtons, Keplers, Darwins, Pascals and Edisons of the to-morrow of science will perforce enter the domain of psychological and social phenomena and develop techniques not less pleasingly scientific than the acknowledged skills associated with the test tube, the compound microscope and the laboratory of the admirably competent but morally and socially circumscribed sciences of material things.

IMMIGRATION AND THE DECLINING BIRTHRATE

By Dr. MAURICE R. DAVIE

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SINCE General Francis A. Walker published his article on "Immigration and degradation" about thirty years ago, it has been rather generally believed among students of the subject that immigration has not increased the population of the nation. According to this point of view, immigration has amounted not to a reinforcement of our population but to a replacement of native by foreign stock. Indeed, it is claimed by one writer that the United States would have a larger population to-day if there had been no immigration since 1820. Some such view of the effect of immigration on population is to be found in most books on immigration, and to-day it is being stressed as an argument in favor of restriction.

The origin of this opinion goes back to one Elkanah Watson, who in 1815 wrote a brief statement entitled, "A view of the progress of the population of the United States." He had been impressed by the rapid growth of population during the two decades following the first enumeration in 1790, and on the supposition that numbers would continue to increase in the same ratio he predicted what the total population would be at each succeeding census up to 1900. He himself noted the actual results until 1840, and when he compared them with his earlier estimates he found that the two sets of figures at each census year practically coincided. His estimates for the following decades, however, proved to be much in excess, and increasingly so, with the widest discrepancy appearing in 1900. Whereas he had predicted a population of one hundred million in 1900, the census report showed only seventy-five million. It is to be noted that immigration at the time when Watson wrote was inconsiderable in amount and that he did not foresee the great influx of immigrants that occurred later. He expected the increase of population to come from excess of births over deaths. In spite of the fact that many million immigrants have arrived, the total population of the United States at each decade since 1840, with one minor exception, has failed to reach the figure which Watson had predicted.

The following table shows these results:

	Watson's Estimates	Actual Result	Watson's Excess Over Actual Numbers	Immigants Preceding Decade
1820	9,625,734	9,638,453	12,719	(No data until 1820)
1830	12,833,645	12,866,020	32,375	151,824
1840	17,116,526	17,069,453	47,073	599,125
1850	23,185,368	23,191,876	6,508	1,753,274
1860	31,753,824	31,443,321	310,503	2,571,036
1870	42,328,432	38,558,371	3,770,061	2,377,279
1880	56,450,241	50,155,783	6,294,458	2,852,191
1890	77,266,989	62,947,714	14,319,275	5,246,613
1900	100,355,985	75,994,575	24,361,410	3,687,564

We have here to consider two phenomena occurring during the same period of time: a relative decline of the native stock, produced by a lowering of the birthrate; and a large infusion of the foreign element, through immigration. General Walker, after comparing Watson's estimates with the census returns, and considering the flow of immigration, came to the conclusion that immigration was the cause and the relative decline of the native population was the effect; that Watson's estimates would have proved correct if immigration had not occurred. "The access of foreigners," he wrote, "at the time and under the conditions, constituted a shock to the principle of population among the native element. That principle is always acutely sensitive alike to sentimental and to economic conditions. And it is to be noted, in passing, that not only did the decline in the native element, as a whole, take place in singular correspondence with the excess of foreign arrivals, but it occurred chiefly in just those regions to which the newcomers most freely resorted."

He believed that the incoming of the foreigner operated in two ways to check the disposition of the native toward the increase of population at the "traditional" rate. The first reason is sentimental:

> Throughout the northeastern and northern middle states, into which, during the period under consideration, the newcomers poured in such numbers, the standard of material living, of general intelligence, of social decency, had been singularly high. Life, even at its hardest, had always had its luxuries; the babe had been a thing of beauty, to be delicately nurtured and proudly exhibited; the growing child had been decently dressed, at least for school and church; the house had been kept in order, at whatever cost, the gate hung, the shutters in place, while the front yard had been made to bloom with simple flowers; the village church, the public schoolhouse, had been the best which the community, with great exertions and sacrifice, could erect and maintain.
>
> Then came the foreigner, making his way into the little village, bringing —small blame to him!—not only a vastly lower standard of living, but too often an actual present incapacity even to understand the refinements of

life and thought in the community in which he sought a home. Our people had to look upon houses that were mere shells for human habitations, the gate unhung, the shutters flapping or falling, green pools in the yard, babes and young children rolling about half naked or worse, neglected, dirty, unkempt. Was there not, in this, sentimental reason strong enough to give a shock to the principle of population?

But there was, besides, an economic reason for the check to the native increase. The American shrank from the industrial competition thus thrust upon him. He was unwilling himself to engage in the lowest kind of day labor with these new elements of the population; he was even more unwilling to bring sons and daughters into the world to enter into that competition. For the first time in our history the people of the free states became divided into classes. Those classes were natives and foreigners. Politically the distinction had only a certain force, which yielded more or less readily under partisan pressure, but socially and industrially that distinction has been a tremendous power, and its chief effects have been wrought upon population. Neither the social companionship nor the industrial competition of the foreigner has, broadly speaking, been welcome to the native. * * * *

If the foregoing views are true, or contain any considerable degree of truth, foreign immigration into this country has, from the time it first assumed large proportions, amounted not to a re-enforcement of our population, but to a replacement of native by foreign stock. That if the foreigners had not come, the native element would long have filled the places the foreigners usurped, I entertain not a doubt. The competency of the American stock to do this it would be absurd to question in the face of such a record as that for 1790 to 1830.

According, then, to the view of General Walker and of the many who have followed him, the native Americans, to protect their standard of living in the competition with immigrants of lower standards, have limited the number of their offspring. It is further claimed that if this lowered rate of increase of the native element had not taken place, our population from native stock alone would have been fully as large as it is now; that, in fact, "for every immigrant who lands in America one less child is born to an American," so that the coming of immigrants when viewed over a long period of time is but a substitution of one race for another.

There is no argument about the fact of the declining birthrate. The census reports show a declining rate of increase of the total population, which has occurred despite the arrival of many million immigrants.

PERCENTAGE INCREASE OF POPULATION OVER PRECEDING CENSUS

1790		1860	35.6
1800	35.1	1870	26.6
1810	35.4	1880	26.0
1820	33.1	1890	24.9
1830	33.5	1900	20.7
1840	32.7	1910	21.0
1850	35.9	1920	14.9

Population showed an increase of approximately one third during each of the seven decades from 1790 to 1860, of one fourth during each of the three decades from 1860 to 1890, of one fifth during each of the two decades from 1890 to 1910, and of one seventh during the last decade.

Since this declining rate of increase has occurred at the same time that the death rate has been declining, and since no appreciable movement of population away from the country has taken place, it argues that the birthrate has fallen off. But that the declining birthrate has been caused by immigration is a matter on which judgment should be suspended until all the facts have been investigated. We must be careful to avoid the common fallacy of generalization known as *post hoc, ergo propter hoc*—a conclusion that because one event takes place after another, it occurs on that account; as, for example, to argue that because night follows day, it follows as a result or consequence of day. This type of fallacious reasoning is usually committed in attempting to explain complicated phenomena by a simpler theory than their nature admits of. There may be strong evidence that the decline in the native birthrate would have occurred anyway, even if there had been no immigration. The growth of immigration and the decline of the native birthrate, instead of being cause and effect, may conceivably be two different effects of the same cause, *viz.*, the industrial development and urbanization of the continent.

The original assumption in the process of reasoning which I am criticizing was made by Elkanah Watson when he assumed that population, immigration or no immigration, would continue to increase in the same ratio. Had he known anything about the law of population, he would not have made such a rash prediction.

The law governing the growth of population is that numbers tend to increase up to the limit of the supporting power of the environment (land), on a given stage of the arts, and for a given standard of living. It is this ratio of population to land that determines the basic conditions of life. If the amount of land is relatively large or is increased, or if the level of the arts of life is raised, population may increase accordingly. The standard of living affects numbers in the opposite way: if the standard is raised, numbers tend to fall off; if lowered, numbers increase.

The early Americans had a lower standard of living than that which now prevails; the stage of the arts was lower, too, but the amount of land relatively to numbers was extraordinarily high. The conjuncture was overwhelmingly in favor of men as against land. Hence the rapid increase of population that was characteristic of our early days. On the frontier where land is plenty and

men scarce, the unoccupied land constitutes a sort of vacuum into which population tends to flow, not only by immigration, but also by natural increase. At the time when Watson wrote, these were the conditions. This was a new and largely unsettled country, the people were engaged mainly in agriculture, there were almost no large cities, and consequently the birthrate was unusually high. Such is always the result in new countries and under pioneer conditions. Marriage takes place early, and children, under the existing conditions of easy support, brief education, scarcity of labor, and the like, are economic assets, where, in a more developed society, they are liabilities. All colonies and new countries in the temperate zone have shown this capacity for rapid growth.

When, later, the country has been brought under the control of man, it naturally follows that the rate of increase, under the new conditions of greater density of population, will decline. No old and densely settled country ever shows as rapid an increase of population as does a new country, and as a new country approaches old-world conditions its rate of increase gradually falls off. The early rate of increase could not be maintained forever unchanged, for as fast as the land is taken up there results a limitation to rate of growth of population. The vacuum ceases to be a vacuum and there is a check on expansion. If the early rate of increase should continue unchanged, it would not take many decades to produce a condition in which there would be more people than the country could possibly support on any acceptable standard of living. It is as absurd to predict the continuance of the same rate of increase of population as to predict that the rate of growth of railroads would continue unchanged. When we began to build railroads about 1830 there was obviously much room for expansion, and as a result the amount of new mileage increased rapidly. There was a period of great extension culminating in 1890 (the year, be it noted, when our frontier was first said to have disappeared); since then the rate of growth has slackened and now new construction has almost ceased. This is exactly what one would expect. So it is hard to escape the conclusion, in regard to population, that the rate of increase would have declined irrespective of immigration. The large family of early days continued just as long as early conditions continued and no longer.

One does not need to resort to a theory that native Americans refused to bring children into the world to compete in the labor market with immigrants, in order to explain the phenomenon of the declining birthrate. There are plenty of other causative factors bearing on that occurrence, most of which are attributable to the changed conditions which have come over the United States.

Our falling birthrate correlates directly with the industrial and social changes of the past half century. We used to be a nation of farmers; we are now a great manufacturing and commercial nation. The majority of Americans once lived in rural communities; now over half of the people live in cities. We used to have great unsettled tracts of land; now we have none. Our density of population was formerly insignificant (4.5 people to the square mile in 1790); while it is still small in comparison with most European countries, it has been increased by many times (35.5 in 1920). All this means a growth of industrialism and of urbanization, and it will be found to explain fully enough the phenomenon of a declining birthrate. In terms of the law of population, it means a less favorable conjuncture of men as against land and also, as will be seen, a rising standard of living.

Let us look a little farther into these modern conditions and observe their effects. Children on the farms are an asset, in cities they are a liability. Children in the country find more work fitted to their strength and are of greater assistance to the family than in the city. Furthermore, the raising of the age for leaving school and allied changes as to work, which apply principally to cities—observe our child labor laws—are preventing children from being an early source of profit. As a result, families in the country are larger than families in the city, and since the proportion of urban population is increasing, the rate of growth of the total population is decreasing. City conditions do not favor a rapid natural increase. The characteristic mode of city growth is by accretion.

There is a marked tendency for a greater proportion of the population to remain permanently single, and for those who marry to postpone matrimony to a later age. This is particularly true of cities, where the expense of housekeeping and child-rearing obliges many to defer marriage. In the country districts single life has not so many resources, such as clubs and amusements; it is more of a bore, and so man is thrown back on domestic life. Besides, a wife is of economic utility. The emancipation of women seems to have proceeded farther in urban communities, and one result of their changed industrial and social status is the tendency to bear fewer children.

The necessity for more expensive training, to fit children to take part in the mental and industrial life of the nation, is also operating as a check on increase of numbers. There appears to be a more vivid realization of the responsibility of parenthood, and higher ambition on the part of parents for their children. As a consequence, parents are perceiving that to give their children advantages they must have fewer children.

The growing burdensomeness of large families and the high cost of living, together with a greater desire for luxury and a general raising of the standard of comfort, have further combined to restrict numbers. There has also occurred a gradual slackening of religious restraints, especially noticeable in cities. But greater than these special causes is the deliberate and voluntary avoidance of child-bearing on the part of a steadily increasing number of married people, who not only prefer to have but few children, but who know how to realize their preference. The desire to improve their social position acts so powerfully upon many families that they are willing to sacrifice anything to obtain this end. These are the considerations that consciously or unconsciously affect the average American, and they, rather than the fear of competition with immigrants, account for the dwindling birthrate.

Observe now the correlation between this explanation of the declining birthrate and the flow of immigration. It is the industrial development and urbanization of the country that has furnished the demand for immigrants, chiefly for unskilled industrial laborers, and as that development has progressed the demand for immigrant workers has increased. This development further explains the fact that the native birthrate has declined most noticeably in those sections of the United States to which immigrants have chiefly gone. The native birthrate appears to be lowest in the most industrialized and urbanized parts of the country, and it is because of those very conditions. And the immigrants are concentrated in those sections for the reason that there the demand for such workers is greatest. If immigration has at all affected the native birthrate, it has done so indirectly by furthering our industrial advancement. So the rapid development of industry, and with it the growth of cities—in a word, the changed type of society in America—is a fundamental cause of both the increasing flow of immigration and the declining birthrate.

At this point it is pertinent to ask which is the real cause of the declining birthrate—competition with immigrants or these changed conditions? If one should still believe that immigration has caused the native stock relatively to decline, what will he say about the following facts? The decreasing birthrate is not solely an American characteristic, but has been a common phenomenon in almost all European countries during the last fifty years or so, and particularly during the latter part of the nineteenth century. Now, if competition with immigrants of lower standard of living has produced the decline in rate of increase of our American stock, how can one explain, on that basis, the fact that the birthrate has declined in other countries where there is no competition with

immigrants at all, but from which the immigrants have come? The real reasons for that decline are the same as the reasons for the decline in America: industrialization and urbanization.

Furthermore, Australia, where the immigration has been slight, and akin to the native population in blood, is lamenting her declining birthrate. In 1902 a commission was appointed by the New South Wales Government to inquire into the causes of the declining birthrate in that country. Its reports stated that in the last thirty years Australia had lost a natural addition of twenty-five thousand. The decrease was to a large extent artificially created, many witnesses admitting deliberate restriction of family. The population of Australia as a whole is not dense, but the proportion of city-dwellers is very high and the birthrate is low and declining without the influence of immigration.

Let me state, further, that the falling birthrate in this country is most marked among the classes who are not in competition with the immigrants. It is a matter of common knowledge that the birthrate seems to vary inversely with the amount of income. The highest birthrate is found among the classes in the lowest income-groups. With these there is thoughtlessness for what the morrow may bring. The alarming reports about the declining birthrate refer mainly to the so-called upper classes. Cattell finds that the average Harvard graduate is the father of three fourths of a son and the average Vassar graduate the mother of one half of a daughter; and that the average family of American men of science is only 2.22 as compared with an average of 4.66 for the country. To increase our worry about these fractional children, Popenoe and Johnson give similar results summarizing many statistical studies of Yale, Harvard and other educational institutions. Surely no one will say that these classes are restricting the number of their offspring on account of competition with low-standard immigrants or because of any "sentimental" reason arising from dislike of the way in which immigrants live.

Moreover, if one will observe the immigrants themselves he will note the same tendency, as time goes on, to have fewer children. The foreign-born have the highest birthrate; the second generation, that is, the native-born of foreign parents, have a lower rate; while the next generation, the native-born of native parentage, have a still lower birthrate. Is competition, which in this case would have to be with themselves or with other immigrants, the explanation, or is this decline among the foreign stock due rather to their increasing prosperity, to their advancing standard of living?

The conclusion is inevitable that Walker's explanation of the declining native birthrate is incorrect. The lessening birthrate

itself, however, is a matter of great significance, to which the attention of the public should be directed. The native population in some sections is barely holding its own, in others it is actually dying out with considerable rapidity. On the other hand, the immigrants and, in turn, their children, are reproducing at a higher rate than the native-born of native parentage. This situation—a differential birthrate—may produce real race suicide, in the sense in which the term was originally used by its inventor, Professor E. A. Ross. That is to say, the native stock may so decline, relatively, that the foreign element will become greater than it in numbers, owing simply to differences in the rate of increase. Dr. Louis I. Dublin has pointed out the real significance of the declining birthrate among the native stock, where two or three children seem to be the rule. In order, he says, for our native stock to maintain itself, without increase or decrease, it is necessary that every married couple have at least four children, for not every person lives to a reproductive age, many people do not marry, and there is a considerable proportion of unions which are sterile. Yet there is much evidence that the best blood of America is being thinned out by the exercise of a conscious limitation of births. If the native stock deliberately and increasingly limits its own increase in this way, and if at the same time the foreign stock exercises a much lesser check on increase of numbers, in time the obvious result of this differential birthrate will be to change the character of the predominant racial type in America. This effect is to be noted without any reference to the comparative worth of one stock as against another. It is not a question as to whether the basic stock in this country is superior or inferior. It is simply a question as to whether, in its own interest, it is to be perpetuated. If America is to remain a nation of predominantly the same stock that it has been in the past, or is now, the admission of more rapidly increasing stocks must be stopped.

Here we find a reason for the restriction of immigration, based not on a supposition that immigration causes a replacement of native by foreign stock, but on a differential birthrate due to differences in standards of living. Since, therefore, we have a reason for restriction which is valid, why should we base our argument on unsound theory like Walker's?

THE DEVELOPMENT OF GEOLOGIC SCIENCE

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The Beginnings of Earth Science

We have slight record of any nature study by the ancient oriental peoples. The old cosmogonies of Chaldea and Assyria, borrowed by the Hebrews, illustrate the psychologic phenomenon of the tendency to search for the remote and the unseen to the neglect of the near and the common.

The active-minded Greeks made an excellent beginning in geology, being free from religious bigotry and not required to shape their thinking to a fanciful and false cosmogony. Their great philosophers during five centuries B. C. were truly scientific, and the science of that time was equal to that of Christianized Europe in the fifteenth century. Some examples are pertinent. Pythagoras, about 500 years B. C., recognized geologic processes and agencies. Herodotus, over 400 B. C., knew fossils to be remains of once living organisms. And Aristotle, over three centuries B. C., grasped the fundamental conception of evolution. The great school at Alexandria, founded about 275 B. C., with its research laboratories in physical sciences, gave serious attention to geography. Following the Greeks a few Romans continued the nature study. Strabo, about 20 B. C., records in 17 volumes his acute observations and shows a broad knowledge of geologic changes. Seneca, 2–65 A. D., described the work of rivers in erosion and deposition, and of sedimentation in the sea; while the elder Pliny was author of 37 volumes in natural history. But " . . . the flicker that Pliny kindled upon the dying embers of Greek learning was allowed to go entirely out."

With the disordered state of the western world, following the ruin of Greek and Roman civilization, the study of nature was forgotten; and for a thousand years it was not only neglected but despised, for early Christianity held the material world to be accursed and expected its quick destruction. Down to the fourteenth century the Arabians were the only people with scientific interest, mainly in physical and chemical study, and in mineralogy. Omar Khayyam, who died about 1123, was somewhat a geologist, but his views were discordant with the Koran; his recantation was demanded, and he went into exile.

In the fifteenth century science shared in the renaissance. The revival of learning brought to light some of the scientific knowledge and conceptions of the free thought of pre-Christian time; the Protestant reformation gave an impulse to research and self-expression; while the discovery of the Americas aroused interest in geography. But, most unfortunately for intellectual progress, Christianity had included in its "sacred writings" the folk-lore and fanciful Mosaic cosmogony of the Hebrews, and invested them with supernatural authority. Discoveries in science were bound to contravene the literal interpretation of such "holy scriptures."

The most unhappy chapter in the intellectual history of the world is that of the persecution of men of science by religious bigotry and intolerance of the Christian church. And Protestants were scarcely less guilty than the Jesuits, although their shibboleth was freedom.[1] And we may not forget that we yet have with us the same ignorant, conceited, bigoted intolerance, but under restraint. Many millions of people in America to-day, in this supposedly intelligent age, regard Genesis as of divine revelation with literal interpretation of its legendary narratives. And most of them think that the Lord dictated it to Moses in the English language.

The pitiful story of the struggle of geology against superstition can not be told here, but a few steps in the progress may be noted. It was not until the middle of the eighteenth century that scientific men in general accepted so evident a fact as the organic origin of fossils. The many absurd explanations would be amusing if they were not so pitiful. It took Europeans over 2,000 years to recover the reasonable mental attitude of Herodotus and Aristotle. And when the organic origin of fossils was finally admitted, another obstruction was laid in the path of mental progress—the fossils were relics and proof of the Noachan deluge; and the battle with religious superstition had to be fought another century.

Leonardo da Vinci (1452–1519) was not only a great engineer and artist, but was one of the founders of modern geology. Another was George Bauer (Agricola) (1494–1555), who has been called the father of mineralogy and metallurgy.

Giordano Bruno was so far ahead of his time in his conception of nature, and so brave in his utterance, that he was burned at Rome in 1600. We honor him as a martyr to science.

The earliest comprehensive writing about the earth was by Kircher (1602–1680). Nikolas Steno, a Dane (1638–1687), recognized the principles of stratigraphy and the fact of deformation of strata into folds and mountains. Archibald Geikie gives great

[1] The shameful story is told in Andrew D. White's "Warfare of Science."

credit to Jean Etienne Guettard (1715–1786), whose voluminous writings were freely used, but with insufficient credit. The first writer to frame a comprehensive account of the earth's history was Buffon, in 1749, for which he was forced by the church to make abject recantation. The great Leibnitz (1744–1829) tried to harmonize Genesis with geology. The religious school of geology in England was represented by John Woodward (1665–1722), who is one of the geologists buried in Westminster Abbey.

The irrational conceit of scholastic theology is illustrated in the writings and sermons of the great and good John Wesley (1703–1791), who taught that before sin entered the world there were no volcanoes nor earthquakes. Earthquakes were the "effect of that curse which was brought upon the earth by the original transgression." Wesley had a sermon on the "Cause and Cure of Earthquakes," which is not listed in our geologic bibliography. Down to about the middle of the nineteenth century, or until Lyell shamed them, it appears that the chief pastime of some theologians was to ridicule geology and to abuse its devotees. Now biology and evolution have relieved geology.

Geology in England

England was always in the front line of geologic progress, and a long list of honored names could be given. Mention must be made of a group of eminent men in the closing years of the eighteenth and first part of the nineteenth centuries. Dr. James Hutton (1726–1797) is regarded as the founder of dynamical geology. Sir James Hall (1762–1831) was the founder of experimental geology. William Smith (1769–1839) was the father of English stratigraphic and historical geology, and of geologic cartography. Roderick I. Murchison (1792–1871) and Adam Sedgwick (1785–1873) described the older strata and applied the names Cambrian, Silurian and Devonian, now in use over the world. The Geological Society of London was founded in 1807.

While these men and others, English and European, contributed largely to the knowledge of the globe it remained for Charles Lyell (1797–1875) to collect the mass of fact and place it before the world in convincing manner. Like his friends and coworkers, von Buch and Humboldt, he had the wealth which enabled him to devote his life to science. He exemplified the saying that the first, second and third requisites of a geologist is travel, visiting America three times. The first volume of his "Principles of Geology" appeared in 1830. Its immediate popularity was shown by the expansion of the third edition, in 1834, into four volumes. By 1875 it had run to twelve editions. The volume 4 (1834), treating historical geology, was

recast in 1838 as the "Elements of Geology," which had six editions by 1871.

Down to Lyell's time the doctrine of cataclysms or catastrophes was commonly held, perhaps chiefly for the reason that it helped to explain the Genesis cosmogony and the story of the deluge. Lyell was the vigorous opponent of catastrophism and he established the doctrine of uniformity. He proved, even for the theologians, that the earth's features are wholly the product of forces and agents now working, and that the past must be interpreted in terms of the present. He marshalled the then-existing knowledge to prove that geologic processes are continuous, and that the present forces, as a whole, are as effective as in the past. While Lyell's uniformitarianism was somewhat extreme, as a reaction from catastrophism, allowing neither beginning nor end to nature's activities, it was essentially true, finding no place for a "flood" or any other supernatural interferences in the material world.

Lyell's teaching found such general acceptance that the way was cleared for the extension of the doctrine of evolution to the organic world. Before Darwin was Lyell. At the age of 62, when many strong men find it difficult to accept new views, Lyell cordially adopted the theory of Darwin, his pupil and friend, and for the tenth edition of his "Principles" completely rewrote the chapters on the distribution of life, accepting the theory of descent by natural selection. Agassiz, only two years his senior, opposed "Darwinism" to the end of his life.

Darwin was a geologist, but his fame in biology has obscured his influence in geology. He made important contributions to stratigraphic and historical geology, especially by emphasizing the enormous length of time and the fragmentary character of the geologic record.

Geology in America before 1848[2]

Status in Education

During all colonial time, and in the period of stress following the Revolution, little attention was given to science of any kind. Down to the second decade of the century the colleges taught almost no science except medicine. And it is an interesting fact that down to about 1870 a large proportion of American geologists were physicians, for the reason that they were the only men with any training that could be called scientific.

[2] The year 1848 is here used as a convenient and critical date of reference, lying near the middle of the nineteenth century, and marking an era in American science through the organization of the American Association for the Advancement of Science.

The first professional position in science was in 1802, when Benjamin Silliman was made professor of chemistry at Yale. The inferior standing of science is shown by the fact that Silliman was then only a law student, 22 years of age, and with no knowledge of the subject he was called to teach. With some preparation he gave his first lecture in 1804, and his subsequent service to science, including geology, justified his selection. During 50 years he was the dominating personal influence, especially through his *American Journal of Science,* founded in 1818.

It is difficult to say when the first chair of geology was established, because the subject was so long included under the omnibus term "Natural History." We know that Amos Eaton lectured at Williams in 1916, and was professor of sciences at the Rensselaer School in 1824. By 1848 several leading colleges had included geology in their courses. In 1850 James D. Dana was professor of natural history at Yale, and not until 1864 was his chair made geology and mineralogy. The giants in geology of those early years were mostly self-taught.

Until 1840 American students looked to Europe, especially to England, for geologic literature and standards. In later years this deference was a detriment to our stratigraphic study and nomenclature.[3] As late as 1837 Edward Hitchcock republished De la Beche's "Researches in Theoretic Geology," a small octavo with no illustrations. The early American books in geology are pitiful in both matter and illustrations.[4] The first important text-book was "Elementary Geology," by Edward Hitchcock, in 1841, which was in America what Lyell's work was in England. By 1860 it had run to 30 editions. The first book to make large use of illustrations was Ebenezer Emmons's "Manual of Geology," 1855. In 1863 all previous text-books were superseded by Dana's "Manual of Geology," which was for 40 years the American geologist's hand-book.

Journals and Societies

The first periodical intended for mineralogists and geologists was the *American Mineralogical Journal,* which endured only four years, 1810–1814. The *American Journal of Science* began in 1818 and retained preeminence as the medium for geologic literature to 1888.

In 1819 the American Geological Society was organized at Yale, with William Maclure as president. This was the earliest society devoted to geologic science, but it survived only to 1828, and published nothing.

[3] See Dr. John M. Clarke's "Life of James Hall," Albany, 1921.

[4] *Science,* Vol. 54, 1921, p. 494.

The Association of American Geologists, organized at Philadelphia, April 2, 1840, was the first permanent society in America, of national scope, devoted mainly to earth-science. This society had its beginning in the Board of Geologists of the New York Geological Survey. Eighteen men participated in the organization. In 1843 the association widened its scope and became the Association of American Geologists and Naturalists. The proceedings of the meetings were published in the *American Journal of Science*, and a volume of 544 pages and 21 plates covering the three meetings of the original society was published in 1843.

In 1847 the society decided to include other branches of science, and the first constitution of the American Association for the Advancement of Science was drafted by H. D. Rogers, Benjamin Peirce and Louis Agassiz, following closely the constitution of the British association. The formal organization occurred at Philadelphia, September 21, 1848, with William C. Redfield as president.

Previous to 1848 the geologic literature was either in the *American Journal of Science* or in the transactions of the following scientific societies: American Philosophical Society, Philadelphia, founded 1769; American Academy of Arts and Sciences, Boston, founded 1780; Academy of Natural Sciences, Philadelphia, founded 1812; Lyceum of Natural History (since 1876 New York Academy of Sciences) founded 1817; Boston Society of Natural History, founded 1830.

Research and Personal Publication

The earliest articles on American earth-science were in mineralogy. The first paper on American geology was published in German, in Germany, by Schöpf in 1787.

Our first paleontologist was Thomas Jefferson, who pursued his study of vertebrate fossils during the years of his active political service, publishing a paper in the Transactions of the American Philosophical Society in 1797.

Not until 1809 did America produce a geologic paper of note. In that year William Maclure, a naturalized Englishman, published as the result of years of intensive field-study and travel over the territory east of the Mississippi, mostly uncharted and in wilderness, his "Observations on the Geology of the United States," including a geologic map. He has been called the father of American geology. This honorable title might be claimed for Amos Eaton, who published in 1818, for the use of classes in Williams College, his "Index to the Geology of the Northern States," which was the first attempt at an orderly succession of the rock strata. In 1830 he published his Geological Text-Book, with colored map.

The earliest geologic "surveys" were also made by Eaton, in New York, of the Helderbergs and Catskills in 1819, and of the "Vicinity of the Erie Canal" in 1823–1824; both being financed by Stephen Van Renssalaer.

With the beginning of official state surveys, about 1830, the necessity for study and publication at personal expense was largely passed.

Official Surveys

This topic has been very interestingly covered by George P. Merrill in chapters III and IV of his "Contributions to the History of American Geology." He states that, by 1849, 20 states had established surveys.

The first survey completed at state expense was that of Massachusetts, in 1830–1833, by Edward Hitchcock. The Rogers survey of Pennsylvania and the epoch-making survey of New York began in 1836. The Canadian survey was established in 1841, and William E. Logan made director in 1842.

The most influential of all the geologic reports was that of James Hall on the "Fourth District" of New York, published in 1843, which established the stratigraphic succession, and its nomenclature, for American Silurian and Devonian.

American geologists before 1848

William Maclure, 1763–1840
Samuel L. Mitchill, 1764–1831
Amos Eaton, 1776–1842
Gerard Troost, 1776–1850
Benjamin Silliman, 1779–1864
Chester Dewey, 1784–1867
Lardner Vanuxem, 1792–1848
Edward Hitchcock, 1793–1864
Ebenezer Emmons, 1799–1863
Timothy A. Conrad, 1803–1877
William W. Mather, 1804–1859
William B. Rogers, 1804–1882
Michael Toumey, 1805–1857
Charles T. Jackson, 1805–1880
David Dale Owen, 1807–1860
Henry D. Rogers, 1808–1866
Charles Whittlesey, 1808–1886
Douglas Houghton, 1809–1845
Oliver P. Hubbard, 1809–1900
Richard Owen, 1810–1890
Increase A. Lapham, 1811–1870
James Hall, 1811–1898
James D. Dana, 1813–1895
Bela Hubbard, 1814–1896

Events and Forces

Publication, in 1809, of Maclure's article, "Observations on the geology of the United States."

The personal influence of Benjamin Silliman (1779–1864), who began teaching in 1804, and founded the *American Journal of Science* in 1818.

The work of Amos Eaton (1776–1842), the early teacher and leader in geology as a separate science.

The organization of the Association of American Geologists in 1840.

Charles Lyell's visits to America, in 1841, 1845, 1852.

The introduction of glacial geology, in 1841.

Emmons's discovery of the Taconic (Cambrian) system, 1841–1842.

The publication of James Hall's Report on the Fourth New York District, in 1843, and three other New York reports.

Description of the structure of the Appalachians by the Roger brothers, in 1842.

The arrival of Louis Agassiz, in 1846.

Publication of the first volume of James Hall's series in paleontology, in 1847.

Footprints in the Connecticut Valley Brownstone

In 1848 the geologists were discussing one of the most interesting discoveries in America. The footprints in the red shales and sandstone of the Connecticut Valley were first called to public attention by Edward Hitchcock, in 1836, who, during later years, made the great collection at Amherst. He diagnosed the three-toed tracks as those of birds, in which opinion the great authorities of Europe concurred. In 1845 Hitchcock had 49 species, 32 of which he regarded as avian. His classic description is the "Ichnology of New England," published in 1858.

In 1860 Mr. Roswell Field claimed that all the tracks were reptilian;[5] and in 1893 the skeleton was found of a dinosaur with the birdlike hind feet.

As the dinosaurs have avian characters, and the archeopteryx is quite as much reptile as bird, it may yet be possible that some of the smaller tracks were made by animals more bird than reptile.

The Taconic Dispute

During the middle of the century the long and bitter conflict over the Taconic question was active. This matter illustrates the difficulties and the progress in stratigraphic geology, and in its nomenclature.

As early as 1841 Ebenezer Emmons announced that he had found strata and fossils in eastern New York and western Massachusetts which were stratigraphically lower, and therefore older, than the Silurian as then recognized. For the new system he proposed the name "Taconic," from the hills of that name in the southern Berkshires. Naturally, such a discovery excited great interest, and many geologists, including the Canadians, studied the area through many years, and with diverse conclusions. The strata were so disturbed, overturned and metamorphosed that the problem was a topic of acrid debate for 60 years.[6] Emmons was treated ungenerously, and wearied and embittered he went to the North Carolina Survey in 1851 and died there during the civil war.

[5] Paper in the *Amer. Jour. of Science*, Vol. 29. The full history of this matter is given by Dr. G. P. Merrill in his Contributions.

[6] A detailed and interesting account of this unhappy episode in American geology is given by Dr. Merrill.

Like all the workers Emmons made errors in his diagnosis of the rocks and of their original position, but his fundamental postulate was correct, and we now recognize his old pre-Silurian system, although under a different name. During the discussion in America a somewhat similar one arose in England, between Murchison and Sedgwick. The latter claimed to have found strata in Wales older than the lowest of the recognized Silurian, and for which he proposed the name Cambrian, from the old Latin name for Wales. And he wished to include in his Cambrian the lower beds of Murchison's Silurian.

Contemporary with this study the great paleontologist, Joachim Barrande (1799–1883), a Frenchman living in Bohemia, discovered a remarkable assemblage of fossils, especially Trilobites, which antedated the organisms of the Silurian; and for this new geologic system he proposed the name Primordial.

Here was a discovery of prime importance in historical geology, made by three men working independently in far-separated lands, at nearly the same time. Priority belonged to Emmons's Taconic. But the American strata were so complicated by disturbances subsequent to their deposition that Emmons, hampered by criticism and jealousy instead of being assisted, was not able properly to limit and characterize the system. While the discussion was on, and with too great deference to British authority and terminology, Sedgwick's name Cambrian came to be used, and has been generally accepted. Similarly, the name Ordovician, another Celtic name, has displaced Lower Silurian; while Silurian is Celtic and Devonian is English. Thus all our period names for the Paleozoic up to the old Carboniferous are borrowed. In the forties James Hall proposed appropriate names drawn from the type areas in New York, which might have been used in America instead of foreign names.

Status in 1848

Up to this time American geology was mainly description and correlation of rock strata and of the contained fossils. The value of the fossils in proving the time-relation of the rocks was fully recognized after the publication of Hall's first volume of paleontology. The students of the science were too busy with the new and captivating stratigraphic features of eastern America to give much thought to theoretic or philosophic problems. They were intent on discovery and description. By 1848 the stratigraphic sequence of the eastern border of the continent was fairly established. The wonderful geology of the far west waited until after the civil war.

The many state surveys were employing the men who were not in college work, but altogether they were few. Of the 461 members

of the American Association for the Advancement of Science listed in the first volume of its proceedings only about 18 names are recognized as those of working geologists; ten of these having been in the parent association (including Vanuxem and Houghton, deceased). And five of the latter were on the New York Survey. This was the day of primitive conditions compared with the present. The latest printed list of the Geological Society of America (1922) includes 477 living fellows, mostly professional geologists, and 123 deceased fellows. And numbers of younger men, and a great number in economic work (especially oil geology) are not yet in the G. S. A.

During the early years a few important dynamical subjects were introduced. The chemical interaction of the atmosphere and the earth's crust were recognized by Vanuxem in 1827; and in 1844 H. D. Rogers made estimate of the storage in the rocks of carbon taken from the air. The yet-active topic of metamorphism was introduced by Dana in 1843, and in 1847 he began the study of a subject yet under discussion—the effects of shrinkage of the globe, the production of mountains and the origin of continents. Amos Binney in 1846 introduced the problem of the loess.

Catastrophism was passing out, and although deference was yet paid to Genesis the continuity and competency of ordinary geologic processes were fairly accepted. The last phase of the cataclysmic idea related to the "drift." Beside the Taconic dispute and the puzzle of the footprints in the sands of Mesozoic time there had been from about 1830 a very animated discussion over the origin of the deposits which we know as glacial. The sheet of rock-rubbish, the moraines, drumlins and eskers, so prominent in New England and New York, were such singular and abnormal features as to be unexplainable by any agencies then known. The geologists were pardonable for invoking tremendous débâcles of water from the north. This fanciful and wild conception had much vogue, but had been jolted by Agassiz's discoveries relating to land ice, which Hitchcock had presented in 1841. The arrival of Agassiz in 1846 gave reinforcement to the glacialists, but the diluvialists were not entirely subdued for some years.[7]

The geologists of 1848 doubtless were proud of their science and of their success in probing the earth. And they were justified. But as we look back on that time their field of geology appears so narrow as compared with the present highly differentiated and complex science; and we note the small area which they had covered, and the little company of workers as compared to the present well-organized army.

[7] See the Proceedings of Amer. Assoc. Adv. Sci., Vol. 47, 1898, pp. 257–290; also *Amer. Geologist*, Vol. 22, 1898, pp. 154–189.

Geology Since 1848

Preliminary Outline

A period of suspense in all scientific work was due to the civil war with the years of stress immediately before and after, 1856–1866.

Previous to the civil war geologic exploration was confined chiefly to territory east of the Mississippi, while since that time the far west has been the field of great discovery. Merrill calls the long period from 1830 to 1870 that of "State Surveys."

Following are some of the more important events in the progress of geology before 1900:

James Hall's series of 15 volumes in paleontology, 1847–1898.
J. D. Whitney's "Metallic Wealth of the United States," 1854.
Permian strata found in Kansas, 1858; in Pennsylvania (published), 1880.
J. W. Dawson's "Acadian Geology," 1855 (3rd edition, 1878).
Pacific Railroad reports, 13 volumes, 1855–1860.
Edward Hitchcock's article on "Surface Geology," 1856.
H. D. Rogers's "Geology of Pennsylvania," two volumes, 1858.
J. S. Newberry's report on the Ives exploration of the lower Colorado Valley, 1859.
Dana's "Manual of Geology," first edition, 1863.
W. E. Logan's "Geology of Canada," 1863.
Discussion of the nature of "Eozoon," 1865–1894.
F. V. Hayden's surveys of the Rocky Mountain region, 1867–1879. (His personal work began in 1853.)
Clarence King's survey of the 40th parallel, 1867–1877.
G. M. Wheeler surveys, 1869–1879.
Joseph LeConte's papers on geophysical problems, 1872–1896.
Discussion of the "Laramie problem," age of the lignites, 1872–1897.
Second geological survey of Pennsylvania (Lesley's), 1874–1887.
J. W. Powell's "Exploration of the Colorado River," 1875, and "Geology of the Uinta Mountains," 1876.
G. K. Gilbert's report on the geology of the Henry Mountains, 1880. (The subject of "Laccolites" noted by Peale in 1875, and taken up by Gilbert in 1877), and his report on Lake Bonneville, 1877–1890.
Establishment of the United States Geological Survey, 1879.
C. E. Dutton's report on the high plateaus of Utah, 1880.
W. P. Jenney and Henry Newton's report on the Black Hills of Dakota, 1880.
Geological Society of America, organized, December, 1888; its Bulletin begun, February, 1890.
N. H. Darton's catalogue and index of contributions to North American geology, 1732–1891. (U. S. Geol. Surv. Bulletin 127), 1896.

Differentiation; Organizations

As in all departments of knowledge geology, with its expansion, has become specialized, and this produces division and multiplication of societies. The American Association was never able ade-

quately to publish and illustrate its geologic papers, and with the interest and growth in geology attending the development of a great continent the geologists organized in 1888 a new, professional society. Accredited Fellows of Section E were eligible as original members of the Geological Society of America, which has become the leading society of the world devoted to geology.

The Geological Society of America has in turn several offshoots: the Association of American Geographers, organized in 1904; the Paleontological Society, 1909; the Mineralogical Society of America, 1920; and the Society of Economic Geologists, in 1920. A branch of the Geological Society, the Cordilleran Section, organized in 1899, has as its province the western part of the continent. The Seismological Society was organized in 1910.

Two other geological societies now exist, the Southwestern Geological Society, with headquarters in Texas; and the American Association of Petroleum Geologists, having a very large membership.

Publication; Literature

From about 1835 until 1888 the state surveys furnished a medium for most of the areal and descriptive literature. In January, 1888, the first distinctively geologic periodical was launched by a small group of men led by N. H. Winchell. This *American Geologist* was carried through 36 annual volumes, to 1895, when it was merged with the new journal, *Economic Geology*.

In February, 1890, the Geological Society issued the first brochure of Volume 1 of its bulletin, with 33 annual volumes now complete, and three volumes of indexes.

In 1893 the *Journal of Geology* was founded by the department of geology of the University of Chicago. *Economic Geology*, as noted above, was begun in 1905.

To-day we have as geologic literature not only the above named journals but the voluminous reports of the many active state surveys, and especially the several series of splendid publications by the United States Geological Survey. The geographical societies and their several journals must also be included in the broad field of study in earth-science.

Exploration; Official Surveys

The decade following 1848 was a time of activity in geologic surveys by the states, and the stratigraphy in the territory east of the Mississippi was fairly known. But the western half of the continent was yet, geologically, a *terra incognita*. During the years 1853–1856 the several national surveys for proposed railroads to the Pacific Coast were accompanied by naturalists and geologists,

and the 13 quarto volumes of the Pacific Railroad reports contain some reconnaissance geology of the far west. Two other government surveys were accompanied by Dr. J. S. Newberry; one, the exploration of the lower part of the Colorado River, under Lieutenant J. C. Ives, in 1857–1858, the report being published in 1861; and the San Juan expedition under Captain J. N. Macomb, in 1859. But Newberry's report on the geology was not published until 1876, which lost him the public credit as the pioneer in the field explored.

During the civil war, science was submerged in strife. Following that struggle some of the released officers of the northern army found in the western explorations a field for their energy and courage. A striking illustration was the venturesome boat trip down the Colorado by Major J. W. Powell, in 1869, an adventure of remarkable daring, the dramatic story being told in his report, 1875.

The surveys which in a systematic way revealed to the public the scientific and scenic features of the Rocky Mountain region were those under F. V. Hayden, during the years 1869–1879. His personal studies of the west began in 1854.

The geological survey of the 40th parallel, under Clarence King, was during 1867–1879, the results comprising seven quarto volumes, 1870–1880.

Another series of contemporary exploration was under Lieutenant G. M. Wheeler, the geographical surveys west of the one hundredth meridian, in 1869–1879. The Powell surveys, personal during 1871–1874, became official in 1875–1879.

Then, in 1879 the several government surveys were combined into one strong organization, the present United States Geological Survey, which in purpose, financial support, influence and efficiency has never been equalled by any other scientific bureau.

It is not permitted to name here all the men of that splendid group participating in the early exploration of our western domain, with the paleontologists who reported on the fossils. Excepting the veterans, W. H. Holmes and J. J. Stevenson, they have all passed away, and are enrolled in the geologists' Hall of Fame.

The explorations in the western part of America, during the years 1870–1900, with the wonderful discoveries in structure, dynamics and in the evolution of the vertebrates, probably make the most brilliant chapter in the entire history of geology. The great development of the science in America is due to its wealth in geologic material. Archibald Geikie has said (2, Introduction, p. vii) that "had the study of the earth begun in the New World instead of the old, geology would unquestionably have made a more rapid advance that it has done."

Stratigraphic Geology

The vertical succession and relative age of American strata are now fairly well known, and only details and minor discoveries remain for future students. In Europe the stratigraphy has been worked out in detail. In the eastern continents the strata are known in a broad way, and any surprises are likely to be of new organisms, especially vertebrates, and of economic deposits.

One of the most debated stratigraphic problems during the later years of the century was the "Laramie." During the years 1872–1897 a lively discussion occurred over the age, whether Cretaceous or Tertiary, of the coal-bearing or "lignitic beds" of several separated areas in the Rocky Mountain region. This discussion involved many of the geologists who were active in the western exploration, and all the eminent paleontologists. Fortunately the debate never became so personal and acrimonious as the Taconic dispute. And it was useful, not only by inciting an intensive and careful study of all the characters of the rather unusual deposits, and in revealing the physical changes in that province, but also in developing some fundamental principles in stratigraphy. The deposits in the detached areas were found to close the supposed gap in the record between Mesozoic and Cenozoic times, changing from marine (Cretaceous) through brackish-water to fresh-water or lake deposits (Eocene Tertiary) as the area had been slowly lifted from sea level. The study also gave a clearer recognition of the relative value of different kinds of fossils, plants, invertebrates and vertebrates as horizon-markers, or evidence of relative age of the sediments; and emphasized the truth that geologic time is continuous, our time-divisions more or less arbitrary, and that somewhere the rocks may constitute a continuous and unbroken record from one great period into the succeeding period. In other words, that great geologic time divisions are not everywhere limited by physical disturbances or unconformities in the strata, but are to be distinguished, like epochs in human history, by the culmination of important physical changes, or by the development of some life-group in the evolution of life on the earth.[8]

An interesting discovery by the western explorations was that vast lakes existed in Tertiary time, formed at different levels during stages of the warping uplift of the Rocky Mountain belt. The thick deposits laid in these lakes hold the lignitic coals and include the Bad Lands (Mauvaises Terres) which show the most remarkable erosion forms. And to these freshwater deposits we owe the preservation of the wonderful mammals of the Tertiary.

[8] The story of the Laramie question has been interestingly told in Merrill's Contributions.

In addition to these "continental" lake deposits it has been found that extensive strata of sandstone and shale, formerly supposed to be marine or at least aqueous deposits, were really accumulated on land surfaces, presumably desert areas; sometimes by wind-action (eolian) and sometimes by storm-wash and sheet-flood from adjacent highlands. Such processes are now illustrated in the arid west. These continental subaerial deposits promise to be important in the complicated history, as they appear to be represented in our eastern Paleozoic record.

Intensive study of the structure and contents of sediments and of sedimentation processes, with contemporary land movements, has given importance to a principle vaguely recognized long ago. We now understand that definite strata may change laterally in character, organic contents, and even in time-relation, due to varying depth of the water and the changing relation to the shore. This subject of lateral changes in the character of aqueous deposits has brought new terms into our geological lingo, such as marine transgression and regression, overlap, offlap, etc. (See Grabau's "Text-Book of Geology," pp. 554–562.)

Paleontology

Paleozoology.—In Europe the life record preserved in the rocks was fairly known in 1848, and the remarkable Cretaceous reptiles and Tertiary mammals had been assigned their classic names. The subsequent European progress has been the filling of gaps and addition of details. The most important single discovery, of biologic interest, was that of the *Archeopteryx* in 1862, and a clearer specimen in 1873. This reptilian bird is sufficient proof of evolution, as a half-way link between reptiles and birds, and would have been a conclusive example for Darwin. An even better evidence for development of species is the series of steps in the evolution of the horse, in America.

In his presidential address at the 28th meeting of the American Association, 1879, Professor O. C. Marsh outlined the history of paleontology from ancient time. He recognized James Hall as the father of invertebrate paleontology in America. Hall's first volume was issued in 1847, and he completed 15 quarto volumes with 4,539 pages and 1,080 plates. This output is exceeded only by that of Joachim Barrande (1799–1883) in description of the fossils of Bohemia, who published 24 quarto volumes, and left material for five others.

If we choose one author as the founder of invertebrate paleontology it should be Lamarck (1744–1829), whose work covered the

early years of the nineteenth century; although Guettard gave considerable attention to fossils a half century earlier.

We regard Cuvier (1769–1832) as the founder of vertebrate paleontology and Thomas Jefferson as its earliest student in America. The early leader and authority was Joseph Leidy (1823–1891). In later years the famous men were: O. C. Marsh (1831–1899), E. D. Cope (1840–1897) and J. S. Newberry (1822–1892). The astonishing exhibits in our great museums are the wonderful reptiles, birds and mammals from the western deposits.

Paleobotany.—The history down to 1885 of this branch is found in Lester F. Ward's "Sketch of Paleobotany." He states that petrified wood was mentioned by Albertus Magnus in the thirteenth century, and by Agricola in 1558. The first notice of fossil leaves was in 1664. The earliest writer on fossil plants was J. J. Scheuchzer in 1709, with von Schlotheim as the earliest strictly scientific worker, during 1801–1820. Ward regarded the development of modern paleobotany as beginning with the use of coal as fuel, about the year 1800.

In 1848 Adolphe T. Brongniart was the recognized authority, his greatest work appearing in 1849. The European paleobotanists to 1885 form an extended list of names famous in the science. The famous Americans were Leo Lesquereux (1806–1889), J. W. Dawson (1820–1899), J. S. Newberry (1822–1892) and Lester F. Ward (1841–1913).

It is found that the progenitors of flowering plants lived far back in Paleozoic time, as a series of forms connecting with cryptogams. The conifers, the largest of our trees, date from the early Mesozoic; while our deciduous tree flora arrived in America in Cretaceous time.

Physiographic Geology; Cartography

Physiography or surficial geology, the science of earth-forms or geomorphy, began with Desmarest (1725–1815), DeSaussure (1740–1799) and especially with Playfair (1748–1819). But in America to the middle of the last century there was little scientific physiography. Descriptions of topographic features were empirical, with small reference to causation or to geologic processes. In 1856 the great Hitchcock in his essay on surface geology, which may be regarded as the beginning of American physiography, did not believe that the Connecticut River had carved all its narrower channel.

The subject was lifted to a scientific plane, with distinctive terminology, by Powell in his report on the Colorado Canyon district (1874), and by the papers of Gilbert and Dutton. The

modern leader, and the dean of American geographers, is W. M. Davis, who, with the help of the Association of American Geographers has made scientific geography a popular branch of education. "Baselevel" and "peneplane" are familiar words in scientific lingo.

The indispensable instrument in all field-work in geologic science is the map; and most useful is the one showing surface relief. The topographic maps of the public domain made by the U. S. Geological Survey, with some cooperation of the states, have been the greatest aid to geology of the last 30 years; and have been the means for popularizing physiography. It is difficult for us to realize the difficulties of the geologist in the early years without accurate maps, and often with no map of any kind. Frequently he had to make his maps. Now the field-worker has the aid of the handsomest maps that engineering science, skilled engraving and artistic printing can produce.

Petrographic geology

At the beginning of the nineteenth century the greatest authority on rocks was A. G. Werner (1749–1817). In the last fifty years the optical and chemical study of the crystalline rocks has become one of the most important and popular branches of science. The optical study became possible through the invention of the refracting prism, by William Nicol, in 1829, along with his production of transparent rock-sections. As a science it began with the memoir by Henry Sorby, in 1858, "On the microscopic structure of crystals." Optical mineralogy has developed with the progress in microscopical technique.

The science was developed by Zirkel and Rosenbusch in Germany, by Michel-Levy, Fouqué and Lacroix in France, and back in England by Teall and Harker. In America the science has been advanced by G. H. Williams, J. P. Iddings and L. V. Pirsson and eminent living workers.

This branch of geology laps over on dynamics, geophysics, vulcanism and Precambrian history. And it has many devotees. The Canadian men with their vast area of old crystallines and rich metallic deposits have emphasized the subject since the days of William E. Logan (1798–1875), who was the director of the Canadian survey from 1842 to 1870, and was the founder of American Precambrian geology.

To-day the science of petrography is changing from the descriptive to the interpretive stage, with its latest field the study of sediments. Its highest development is the optical work in the geophysical laboratory.

Glacial Geology

The romantic story of the development of glaciology in America, and the persistence of cataclysmic notions of the "drift," has been told in the *Proc. Amer. Assoc.*, Vol. 47, also in the *American Geologist*, Vol. 22, pp. 154–189.

Glacial science began in 1841 with Agassiz's paper before the Geological Society of London, and in America the discussion began over Hitchcock's address as retiring president of the Association of American Geologists, in 1842. In that address and in other writings

> Professor Hitchcock seemed to declare his adherence to the glacial hypothesis, as applied to America, with as little hesitation and qualification as would be expected of a careful man of science in espousing a new theory that antagonized the prevailing belief and prejudice of his fellow-workers. It is evident from subsequent records that his utterances were accepted at the time as committing him to the acceptance of the theory of Agassiz. But unfortunately . . . the circumstances and scientific forces of that time did not allow him to stand upon the advanced ground he had taken.

There were forces opposing the new theory which were not of scientific character.

> Agassiz was a comparatively young man and quite unknown in geology except for his studies of glaciers. How could his opinion weigh against those of the giants in geology? Another power, which will scarcely appear in the scientific writings of the time, but which was a great conservative force, was theological opinion. All hypotheses invoking water as the drift agency might be harmonized with belief in the Noachan deluge, but the Bible gave no countenance to an ice deluge. To explain it away was little better than heresy. . . . Furthermore, the diluvial hypotheses were unduly deductive, and like all opinions not based on observational or inductive evidence did not readily yield to arguments derived from facts. The older geologists had made up their minds and that settled it.

The acceptance of the glacial theory by any number of Americans could not have been earlier than the personal advocacy by Agassiz and Guyot in 1848 to 1850, although in some qualified form it was adopted by independent thinkers like Conrad and Vanuxem. The general acceptance of the theory, and the use of it as a basis for systematic work and investigation, required 20 years more.

This branch of geology reaches over to meteorology on one hand and to dynamics and geophysics on the other. Glaciers are meteoric phenomena, but are geologic agents. The surface features produced directly or indirectly by glaciation are exceedingly interesting, and are the most effective for popular appeal in regions where they occur. To geologists the subject has lost its element of mystery. We now see that continental ice-fields are as natural as lakes, and normal to areas of excessive snowfall instead of rain. They are essentially local phenomena, dependent on temperature and pre-

cipitation. The latest American continental ice-cap had its origin and its center or radial outflow in southern Quebec. As yet we do not know how much effect a supposed greater elevation of the land had on the initiation of the glacier.

We regard the present time as a part of the Glacial Period, and perhaps as an interglacial epoch. There are good reasons for believing that since the Quebec glacier disappeared the climate of North America and of western Europe has been much warmer than it is to-day. The cause or causes of change in world climate remains a problem. It may be related to the variable content of the atmosphere, especially the carbon-dioxide, with the cooperative factors of continental elevation, paths of cyclonic storms and oceanic circulation. There is little scientific basis for appeal to extra-terrestrial forces for explanation of long-period differences in climate. The problem must be studied as a geologic matter.

The most important discovery in glaciology is the fact of heavy glaciation in former geologic periods, even as far back as the pre-Cambrian. The greatest and most wide-spread glaciation appears to have been in the southern hemisphere, in Permian time, at the close of the long Paleozoic Era. It is suggested that this may be related to the impoverishment of the atmosphere in CO_2, by the withdrawal of carbon in the accumulation of the vast coal deposits. Here glaciology passes over into climatology.

Since the Quebec glacier disappeared the glaciated area has risen, in dome-shaped uplift, at least 1,000 feet at the center. This suggests a causal relation of the land uplift to the unloading from the area of 10,000 feet of solid water. This implies a high elevation of the area before it was loaded and depressed. Here the study passes over into geophysical geology, as an argument for isostasy.

Cosmic Geology

When the Copernican theory was generally accepted, in spite of persecution which lasted far into the nineteenth century, a scientific cosmogony was sought, to express the new knowledge of the structure and motions of the solar system. Suggested by Swedenborg and outlined by Kant, the "nebular" hypothesis was given standing and authority by Laplace, assuming certain primitive conditions. Probably no philosophic conception has ever received such universal acceptance by the modern world as the Laplacian theory. Yet it is not true. It has been conclusively shown by Professors Chamberlin and Moulton that the theory breaks down at every point where attacked by present-day physics and kinetics. The conception of an originally molten globe must also be discarded.

A substitute for the old philosophy, which was good for its day,

has been formulated by Professor Chamberlin. His planetesimal theory builds the earth by the slow infall or accretion of cold particles (planetesimals), and keeps the growing globe always cold at the surface.[9]

This subject is of fundamental importance in geology, because few topics can be carried to conclusion without reference to the origin of the globe. And geologic science has been seriously hindered by the false conception of a molten globe. This new conception of the earth, as having been slowly built by accretion of cold matter, always cold at the surface, and containing within the growing mass all the materials for its slowly formed envelopes—the ocean and atmosphere—gives a rational basis for solving many geologic problems which were insoluble under the old theory.

A few examples of such problems are: (1) the great shrinkage of the globe in late geologic time and under present temperature; (2) the origin of the ocean and atmosphere; (3) the primal source of the vast storage of carbon in the later rocks; (4) source of the enormous volume of volcanic water; (5) the climatic variations during geologic time; (6) the great length of time required for organic evolution.

A brief comparison of the old and new theories will show their fundamental opposition. The old hypothesis assumes an originally hot globe with shrinking on account of cooling. The new regards the globe as originally and always cold at the surface, and the interior heat as the product of gravitational condensation. The old view requires continuous cooling of the globe, while the new allows the conception of increasing internal heat. The old makes the earth of largest size at birth, and of diminishing volume by loss of heat, while the new regards the earth as beginning with a small nucleus and slowly growing by surface accretion; but with large reduction of volume by compression and expulsion of vapors during and subsequent to growth. The old postulates a primal, heated atmosphere and ocean. The new derives the fluid envelopes from the earth's interior by a slow process of expulsion due to heat and pressure.

That the great majority of educated people, and perhaps most of the geologists, yet adhere to and refer to the discredited "nebular" theory, with its molten earth, only illustrates that scientific men are conservative, like other people, and slow to change long-accepted views. Moreover, the attention of the whole world has been diverted from philosophic science and is absorbed in applied

[9] A statement of the planetesimal theory is given in Chamberlin and Salisbury's "Geology," Vol. 2, and in many of Professor Chamberlin's writings. On its application to geology see Bulletin of the Geol. Soc. Amer., Vol. 15, 1904, pp. 243–266.

science, business and politics. It must be realized that knowledge of geologic science is the possession of only a small portion of Americans and Europeans, while a yet smaller number have any special interest in it.

Geophysical Geology

Perhaps the liveliest branch in present-day geology relates to the structure, composition, stresses and movements within the earth.

Sir John Herschel (1792–1871) recognized the sinking of oceanic areas under loading by sedimentation, with the consequent rise of continental areas. As early as 1847 Dana discussed the effects of the earth's contraction from the supposed molten state, and the resulting relief features of the globe. In 1857, at the Montreal meeting of the association, James Hall discussed the subject of crustal movements and mountain formation, which caused debate and criticism, but the paper was ahead of time and was not published until 1882.

Opinions down to the year 1896 on the mechanics of the earth's crust, as shown by earthquakes, mountain structure and continental relief, will be found in three addresses by Joseph LeConte; his presidential address to the association in 1893; his memoir of Dana, 1895; and his presidential address to the Geological Society in 1896.[10]

Le Conte's views, like those of Dana, were based on the conception of the globe cooling and solidifying from a molten and incandescent state.

In 1880, as a result of his study in the high plateaus of Utah, Major C. E. Dutton formulated his theory of isostasy, which postulates an equilibrium of weight or pressure in the earth's crust, with readjustment by subcrustal flow when adjacent areas became unbalanced by loading or unloading. The common illustration at the present time is the unloading by erosion of elevated areas and the piling of the detritus as a load on delta tracts. In essentials isostasy is generally accepted as a working theory. It finds recent illustration in the post-glacial rise of the glaciated areas of America and Europe.

Earthquake vibrations indicate that the entire globe is solid and of high density. As the average specific gravity or mean density of the globe is 5.6, while the observable crust is only 2.8, it follows that the deeper mass has a high compensating density. Whether this greater density is due to compression or to heavy, or metallic, materials is the problem.

[10] Bull. Geol. Soc. Amer., Vol. 7, 1895, pp. 461–474; Bull. Geol. Soc. Amer., Vol. 8, 1896, pp. 113–126; Bull. Geol. Soc. Amer., Vol. 26, 1915, pp. 47–57.

Geologists and physicists have now under intensive study the mechanics of movements in the earth's crust and the formation of mountains by deformation of strata.

Evolution

By 1848 physical evolution, the development of the globe by natural processes, was generally accepted by educated and free-thinking men. But the acceptance of organic evolution awaited the long discussion following Darwin's work.

The study of fossil organisms clearly indicates the development of new forms from old. Living forms, both plant and animal, represent the diverging branches of the life-tree, of which the trunk and the connections are buried in the dead past.

The fossil proofs of evolution are more conspicuous, or at least better known, in the vertebrates, because the latter are more familiar to us in their structure and relations, but students of the invertebrates find that many groups, as the brachiopods, cephalopods and echinoderms, clearly attest the evolutionary process.

The vertebrates are closely related in progressive series. The evolution of birds from reptiles is established by transition forms, such as the dinosaurs, the toothed birds and the linking *Archeopteryx*. The exploration of our western domain has given to paleontology a most surprising abundance of related mammalian remains, which prove the development by inheritance of characters of the various groups of living mammals. This is particularly evident in the ungulates (hoofed mammals). The most striking example is the evolution series of the horse, which in America during Tertiary time evolved from a diminutive five-toed creature to the modern horse, possessing the most highly specialized foot, with a single digit. The even-toed ungulates, especially the ruminants, also give excellent illustration of evolution.

The history of life on the earth, as recorded in the rock-record of scores of millions of years, establishes the truth of evolution since Cambrian time. But that is only the latter part of the process, for the Cambrian organisms represent perhaps more than half of life development from primitive forms. The record of the long earlier stages of organic evolution is lost through the alteration and metamorphism of the pre-Cambrian strata.

The origin of life, or its initiation on our planet, yet remains a problem for biochemistry and scientific philosophy.

All future discoveries will only accumulate proofs of evolution. The devotees of unscientific beliefs and supernaturalism will receive no comfort from discoveries to come. Evolution has passed the theoretic stage and must be recognized as fact. That multitudes

of people do not yet accept it does not affect its status. Scientific truth is not dependent on belief nor to be decided by majority vote. Some people even to-day deny the rotundity of the earth. The cause or method of evolution is uncertain.

While people educated in science may accept evolution as true for all forms of life below man, many of them, and perhaps even some professional men of science, react against including man in the natural process. The false expression "from the monkey" is partly responsible for the prejudice. But the very narrow gap between the higher living primates and the genus Homo may be closed almost any day by new discoveries. Already we have a number of suggestive semi-human fragments. It should be realized that only a small part of the world has been carefully examined, and a large part of the orient, the probable field of human development, not at all. America and western Europe have been explored, but the vast areas of Asia and Africa are the hopeful fields. The "missing link" may not long be missing.

Economics: Present tendency

In later years the United States Geological Survey and most of the state surveys have been compelled to defer to the world-dominating spirit of commercialism. The greater part of all the literary output of the surveys now relates to the economic resources and their utilization. This is in unhappy contrast with the early years of the national survey, when the dramatic exploration of the great west, and the inspiring reports of Hayden, King, Wheeler, Newberry, Powell, Gilbert, Russell and others, with the paleontologic memoirs of Meek, Leidy, Cope, Marsh, Newberry and Lesquereux had a popular appeal to a multitude of readers. The work and reports of those years were educational in the true sense.

The progress in economic geology has largely been the discovery and exploitation of our stores of iron, coal, hydrocarbons, with admirable study of water supplies. Only the last is renewable. Of course modern civilization requires steel and fuel, but it is not necessary to develop our resources so rapidly and wastefully, with little regard for posterity. The exploitation has too largely been not for immediate human need, but for unreasonable private profit. In justice to the national and state surveys it must be said that their influence has been used for conservation of mineral resources; but unfortunately their function to point out the useful products is not accompanied by sufficient power to control production and waste.

In the present darkness the New York survey stands as an intellectual and altruistic beacon. During the 60 years of direction

by James Hall, the few years by F. J. H. Merrill, and the 18 years by John M. Clarke, the State Museum and the State Geological Survey have held steadily to their function of serving the scientific interests of all the people. Most of the vast literature issued from Albany during 80 years is "pure science," in the sense of being non-commercial. Yet New York has important economic mineral deposits, and it is possible that the excellent economic work of the New York Survey might be somewhat increased in proportion to the non-economic.

Problems

The "unknowns" of the earth-laboratory have been reduced to a few groups of questions. The stratigraphic record of the earth's history since pre-Cambrian time, which was the early geology, now offers only details for future study. In the life history the larger elements are established.

The inevitable question, "How long ago?" can not yet be answered. The length of geologic time is not of practical importance, and is so great that, if we knew, it could not be appreciated. However, some time we may yet discover a yardstick for cosmic and geic time. Fragments of glacial time, and perhaps of more ancient periods, may be estimated by the diurnal and annual periodicity of sedimentation. By the lowest estimate the stratified rocks represent over 100,000,000 years.

Some of the geophysical problems have been noted. The composition, structure, temperature and movements of the earth's mass are live topics. Allied to these is the group of problems of the Precambrian, like metamorphism, the ancient effects of which are evident in the exposed crystalline rocks. Under the planetesimal theory the volcanic phenomena and the deep ore deposits are less mysterious. Earthquakes, explained by modern physics and measured by instruments, give suggestion of the earth's interior conditions.

The cause and behavior of the movements in the crust of the globe is an interesting and yet elusive problem, of which the formation of mountains by compression or folding is an important element. Another easily appreciated problem is the causation of climatic variations during all recorded time.

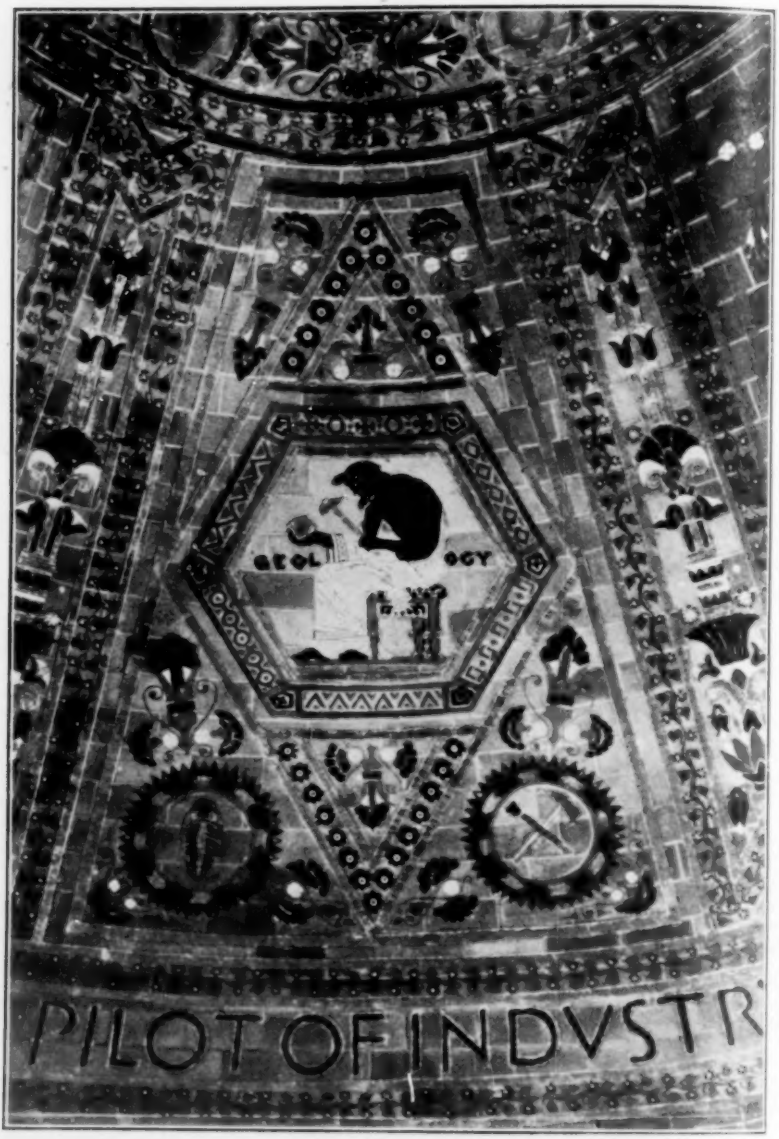
All these questions are related to the fundamental problem of the manner of formation of the globe. It is confidently believed that the theory of slow growth by cold accretion will facilitate the solution of nearly all geologic problems.

All "progress" is a matter of relativity. In his address in 1841 Edward Hitchcock said:

> And now, looking back . . . I am astounded and delighted at the progress of American geology; and it seems to me more like a dream than a reality. . . . .

This was spoken when the Association of American Geologists was one year old, and before the publication of the epoch-making reports of the New York survey and other important state reports. His thoughts in 1848 are not recorded.

We may query if the experts in earth-science 75 years hence will regard our present status with the respectful superciliousness which we have for that of 1848. It does not seem probable. But possibly some of the youngest readers of this article can make report in 1998.



DECORATION ON THE DOME OF THE NEW ACADEMY BUILDING

Emblematic figures representing all the branches of science decorate the interior of the dome of the new academy research building just completed in Washington as the home of the National Academy of Sciences and the National Research Council. A dedication of the building to science is contained in the inscription, partially reproduced in the photograph: "To science, pilot of industry, conqueror of disease, multiplier of the harvest, explorer of the universe, revealer of nature's laws, eternal guide to truth." The portion done in gold, purple and other colors shown in the photograph is a classical representation of geology, a seated figure tapping a rock with a geologist's hammer. The medallions show one of the best known fossils, a trilobite, and the familiar crossed hammer and chisel symbolic of mining.

THE PROGRESS OF SCIENCE

By Dr. EDWIN E. SLOSSON

SCIENCE SERVICE, WASHINGTON

COOPERATION IN LOW LIFE

THE more we learn of animal and plant life, the less it seems like a chaos of incessant conflict and carnage, and the more it seems like a universal scheme of unconscious cooperation. The struggle for existence is real, war to the death, to the strongest belong the spoils, every one for himself, the weak to the wall, and all that. But also we find on closer inspection more than we thought of mutual aid, not only between individuals of the same family or pack or species, but between species of the most widely different sorts, and sometimes it turns out that what seem to be inveterate enemies are actually involuntary allies.

Many an animal owes his success in life to the unrecognized cooperation of the humblest creatures. For instance, it is a great advantage for fishes and other marine forms to have a lighting system for use at night and in the depths of the sea. Some have glands that secrete the two kinds of chemicals that produce light when mixed. But many others depend upon luminous bacteria, of which some thirty species are known. These live in certain glands or stream through tubes which serve as lamps to the lost. The cuttle-fish has gone so far as to fix up a reflector behind and a lens in front of its light-giving colony of bacteria. In the glow-worm the bacteria are also present in the beetle's eggs, which are likewise luminous.

Bacteria and other micro-organisms are often found aiding digestion by attacking substances that their hosts would find too tough to tackle alone. Vegetable foods, for instance, contain more or less cellulose, wood fiber, which is extremely indigestible stuff, and even cattle could not get nutriment out of it if it were not for a process of internal fermentation. The so-called "white ants," termites, terror of the tropics, get their living by eating the insides out of furniture and books, yet they can not digest such cellulose. What they do is to chew it up and turn it over to fungi, which thrive on it and then the termites feed on the fungi.

Flies lay their eggs in meat, but the larvae when they hatch out can not digest the meat without the help of the bacteria in their intestines. Peas, beans and alfalfa owe their power of utilizing the nitrogen of the air to the bacteria that colonize on their roots in the form of nodules. Most plants can not use free nitrogen but have to have it served up to them in the form of salts such as nitrates. The root nodules therefore might be called the Muscle Shoals of the plant world, but that would not be a fair name for them since they are working.

The tubers of the potato are due to a parasitic fungus. Potato seeds planted in sterilized soil do not produce tubers, but when the fungus is allowed to invade the soil tubers start to grow. If you should ask a young potato plant whether it wanted to be infected by a fungus, and if the potato were as intelligent—or rather as unintelligent as men are—it doubtless would reply that its pristine purity must remain unimpaired by any parasite. Yet that refusal would deprive the plant of its chance of per-

FOUNDERS OF SCIENCE

Men of science who have contributed most to the advancement of science during the centuries, portrayed in bronze relief on the front of the building of the National Academy of Sciences and the National Research Council, erected in Washington at a cost of $1,450,000 and dedicated on April 28. The photographs here reproduced are copyrighted by the National Academy of Sciences and released by Science Service.

Francis Galton (1822–1911), English man of science, founder of eugenics; Josiah Willard Gibbs (1839–1903), American mathematician and physicist who applied the principles of thermodynamics to chemistry; Hermann von Helmholtz (1821–1894), German physiologist and physicist; Charles Darwin (1809–1882), the great biologist; Sir Charles Lyell (1797–1875), who laid the foundation of modern geology; Michael Faraday (1791–1867), English chemist and physicist, who discovered magneto-electricity and the magnetization of light.

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Alexander von Humboldt (1769–1859), German philosopher and traveler; John Dalton (1766–1844), English chemist who originated the atomic theory of matter; Jean Baptiste de Lamarck (1744–1829), the French naturalist; James Watt (1736–1819), Scottish inventor of the condensing steam engine; Benjamin Franklin (1706–1790), American patriot and physicist; Christian Huygens (1629–1695), Dutch physicist and astronomer who proposed the wave theory of light and discovered Saturn's rings.

ennial life and, what's worse, deprive us of potatoes. It has been found that orchid seeds do not sprout unless a certain fungus is present, and each species of orchid has to have its particular species of fungus.

The lichen on a tree or stone seems to us a simple single growth, but it really is a partnership of two very dissimilar forms of vegetation, a plant and a parasite, an alga and a fungus. Which is to be regarded as the host and which the parasite, which was originally the patient and which was the disease, can hardly be determined since the relation varies in different lichens, and the two strange associates have been living together so long now that they play into each other's hands and could hardly stand it to live alone.

So it happens that a plant or animal gets used to a chronic disease and finds it advantageous, and a parasite that came to prey remains to serve. Dr. Nuttall, of Cambridge, who at the Liverpool meeting of the British Association for the Advancement of Science gave these and many other instances of cooperation, or symbiosis as biologists call it, thinks that they all began as cases of parasitism, but that the conflict between the associated organisms ended in mutual adaptation. The two enemies become allies and the parasite becomes a partner.

TAMED INVENTIONS

COMING inventions cast their shadows before. Some of the most useful of the gifts of science were first revealed to mankind in a malevolent rather than a benevolent aspect. But even the most destructive agencies may in the course of time be brought into the constructive service of the human race. As the wolf was tamed into the faithful dog and the wild elephant converted into a beast of burden, so man may tame the engines of war and extract medicaments from the most baneful drugs.

Steel, man's most useful metal, made its appearance in the form of swords and spearheads for the killing of man. Now we employ it for the skeleton of skyscrapers and steamships.

Petroleum was first employed as "Greek fire" for setting ships on fire. Now it is employed as fuel for the propulsion of ships.

The horse was employed upon the field of battle long before he was put to work upon the harvest field. He was first hitched to a war chariot and only later was he set to the humble and useful task of pulling a plow. Judging by the Egyptian and Assyrian inscriptions, the chariot was the first wheeled vehicle, but this developed in the course of centuries into the cart, the carriage and the car.

The most efficient of the ancient road builders, more efficient indeed than most modern peoples, were the Romans, and their famous system of highways, connecting the frontiers of the empire with the forum of the capital, was designed for armies, not agriculturists.

It has often happened in history that what was designed to kill is retained to cure. Many of our modern medicines were employed by savages for poisoning their arrow points. Strychnine and aconite had this ill-omened origin. Another arrow poison, obtained by the savages from cassava juice, is hydrocyanic acid, which in the hands of the modern metallurgist extracts nine tenths of the gold supply of the world. Arsenic, which during the Renaissance was the fashionable means of poisoning people, is now used for the more laudable purpose of poisoning plant pests and the parasites of man. Distilled alcohol, introduced by the alchemists under the misleading name of the "elixir of life," has done untold harm

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Galileo Galilei (1564–1642), the Italian astronomer and physicist; Leonardo da Vinci (1452–1519), the Italian painter, architect, sculptor, engineer and anatomist; Hipparchus (about 150 B. C.), the greatest astronomer of antiquity, a Greek who discovered the precession of the equinoxes, founded trigonometry and compiled the first star catalogue; Democritus (about 400 to 357 B. C.), the Greek philosopher who advanced a theory of the formation of the universe by atoms in motion; Thales of Miletus (640–546 B. C.), the Greek physical philosopher, founder of Greek astronomy and philosophy.

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Hippocrates (460–about 357 B. C.), Greek philosopher and "father of medicine"; Aristotle (384–322 B. C.), Greek philosopher who founded natural history as a science; Archimedes (287–212 B. C.), Greek mathematician and physicist; Nicolaus Copernicus (1473–1543), Polish astronomer who expounded the planetary system; Andreas Vesalius (1514–1564), Belgian anatomist; William Harvey (1578–1657), English physician who discovered the circulation of the blood.

to the race. Yet when our gasoline supply runs short, alcohol may prove to be our main reliance for autos and airplanes. Once the world stops drinking it we will have alcohol to burn.

We owe our wireless to the late war, and the art of aviation, which played an important part in that conflict, has not yet found a place of importance in civil life. Government itself is a war baby, born from the need of unified control in time of danger. The earliest rulers were the chiefs who defended their folk against attack or led them on predatory raids against their neighbors for the procurement of booty, especially women and children.

Government, once started as a war measure in emergencies, proved useful for the maintenance of order and the promotion of the general welfare, and hence came to be regarded as indispensable to civilization. But war remains the principal function of government even in the most peaceable of nations. Our own federal government in 1920 spent 93 per cent. of its revenues on wars, past, present and future, while devoting one per cent. to the scientific research and developmental work.

Never before has the world seen such feverish activity in scientific investigation and invention as during the Great War; never such liberal governmental support; never such enterprise and self-sacrifice on the part of the citizens. And so it has often been in the past. Mars has always been able to enlist the energies of man with more success than Minerva or the Muses. Shaw, who sometimes assumes the rôle of the devil's disciple, has in his "Man and Superman" put into the mouth of Mephistopheles a caustic comment on war as a stimulus to man's inventive powers: "I have examined Man's wonderful inventions. And I tell you that in the arts of life man invents nothing; but in the arts of death he outdoes Nature herself, and produces by chemistry and machinery all the slaughter of plague, pestilence and famine. The peasant I tempt to-day eats and drinks what was eaten and drunk by the peasant of ten thousand years ago; and the house he lives in has not altered as much in a thousand centuries as the fashion of a lady's bonnet in a score of weeks. But when he goes out to slay, he carries a marvel of mechanism that lets loose at the touch of his finger all the hidden molecular energies, and leaves the javelin, the arrow, the blow pipe of his fathers far behind. In the arts of peace man is a bungler. I have seen his cotton factories and the like, with machinery that a greedy dog could have invented if it had wanted money instead of food. I know his clumsy typewriters and bungling locomotives and tedious bicycles; they are toys compared to the Maxim gun, the submarine torpedo boat. There is nothing in man's industrial machinery but his greed and sloth; his heart is in his weapons."

But, as we have seen, the bright ideas that have been struck out of man's brain in the clash of conflict may persist to enlighten the race. "God hath made man upright but they have sought out many inventions" for the purpose of doing injury to their fellow-men, but often these have, like Balaam's curse, turned out to be blessings. Though we may regret that science should so often show her sinister side, yet we must agree that civilization does sometimes go forward by riding on a powder-cart.

CHEMISTRY AND THE ALPHABET

WHEREIN is modern civilization superior to ancient civilization and primitive barbarism? In what respects is the man of to-day ahead of his primitive forebears? Probably not in physique or mentality. If the winners of the Olympic games could be matched against our own athletic champions, we should not know which

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Sadi Nicolas Leonard Carnot (1796–1832), French engineer and physicist; Claude Bernard (1813–1878), French physiologist; James Prescott Joule (1818–1889), British physicist who determined the mechanical value of heat; Louis Pasteur (1822–1895), French scientific man who founded the science of bacteriology; Gregor Johann Mendel (1822–1884), Austrian priest who discovered the law of inheritance which bears his name; James Clerk Maxwell (1831–1879), Scottish physicist who propounded the electro-magnetic theory of light.

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René Descartes (1596–1650), French mathematician and philosopher who invented analytic geometry; Sir Isaac Newton (1642–1727), British physicist and mathematician who discovered the law of gravitation; Carolus Linnaeus (1707–1778), Swedish botanist who devised systems of classification for animals and plants; Anton Laurent Lavoisier (1743–1794), French chemist, called the "father of scientific chemistry"; Pierre Simon Laplace (1749–1827), French mathematician and astronomer who formulated the nebular hypothesis; Georges Cuvier (1773–1838), French naturalist who founded comparative anatomy and vertebrate paleontology; Karl Friedrich Gauss (1777–1855), German mathematician.

side to bet on. If a Binet-Simon-Stanford intelligence test were put to a Roman consul, a Phoenician merchant, or an Egyptian priest, I presume he would score high.

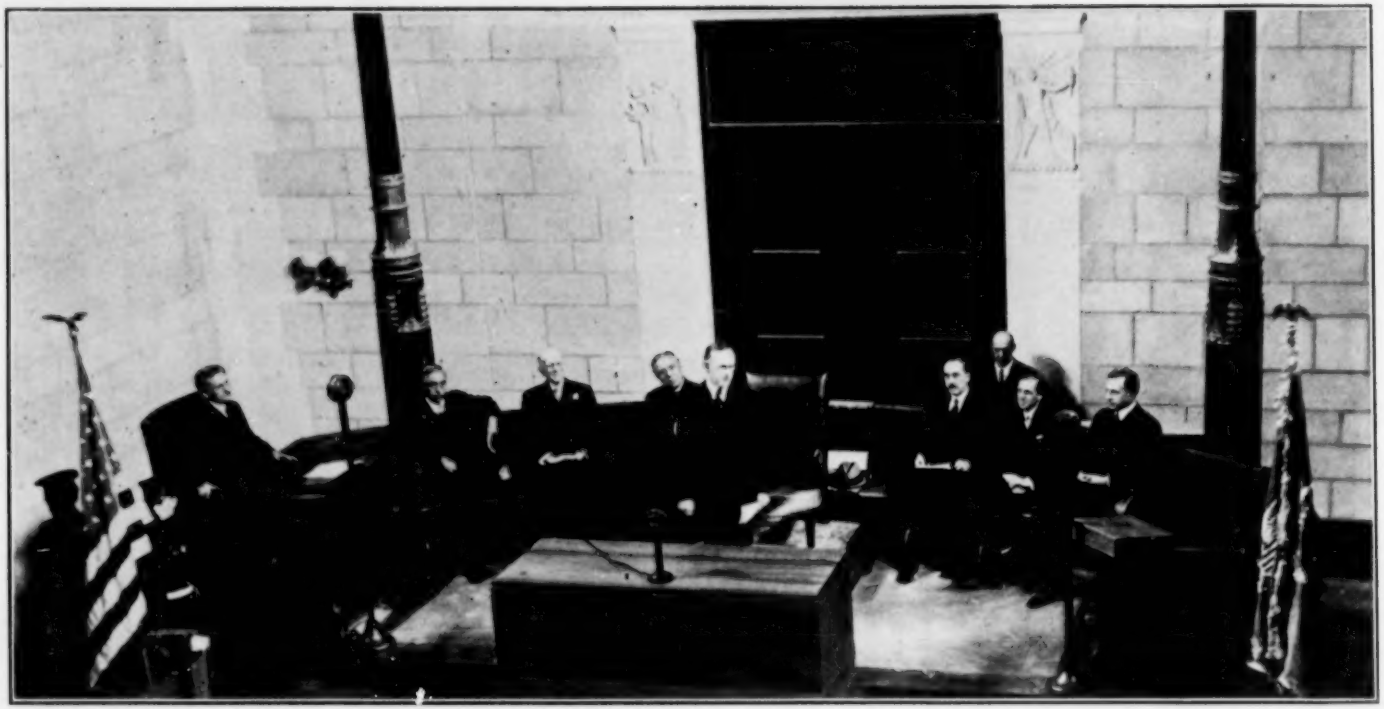
But a man in modern times, even though he may be comparatively weak in body and dull in mind, knows more and can do more than the strongest and the brightest of men in former times. He knows more because he has at his command the accumulated knowledge of the ages, selected, tested and arranged for his benefit. He can do more because he can supplement his feeble muscles with engine power. He can travel fifty times as fast, accomplish a hundred times as much work in a day, lift a weight a thousand times as heavy, and make his voice heard ten thousand times as far. Both these advantages, the physical and the intellectual, he owes to chemistry. It is chemistry that has given him the power that runs his engines and the metals that make his machines. It is chemistry that has given him books; the paper, the ink, the type and the alphabet.

It is a strange thing, and when you think of it a very lucky thing, that substantially the same alphabet is used nearly all over the world, in Europe, the Americas, Australasia and a large part of Asia and Africa. How did it happen? Why should we not get along without an alphabet as the ancient Egyptians did and as the Chinese do? Ask any schoolboy to whom we owe the alphabet and he will reply, if he be of the Macaulay kind that answers rhetorical questions offhand, that the Phoenicians invented it. But if you ask him the natural next question why the Phoenicians, who left us no literature, should have yet supplied the means by which our literature is expressed and preserved, you will probably stump him. That is because history has not been interpreted from a chemical standpoint.

The Phoenicians invented the alphabet because they needed it in their business. And what was their business? Chemical industries and commerce in chemical commodities. With a trade extending from the foggy and barbarous islands of northwestern Europe where tin was mined to the sunny islands of southeastern Asia where spice was grown, with dealings in dozens of different languages and accounts to keep in varying rates of exchange, the Phoenicians had to cut down the cumbrous hieroglyphics to simplified forms and to reduce their number from a thousand to twenty-two. The basis of almost all the alphabets of the world is the commercial code of the Phoenician traders.

And how did the Phoenicians gain their commercial supremacy? How did the Twin Cities of Tyre and Sidon get their start? Let us take the story as it stands in the ancient version.

Once upon a time Hercules was engaged in his favorite pastime of courting a nymph. Tyrus was her name, and as she walked along the Syrian shore, Hercules followed her, and his dog followed him. When he caught up with her he urged his suit, but she continued to refuse. Suddenly she interrupted his impassioned plea with the irrelevant remark: "Oh, just look at that dog!" Hercules looked around crossly and saw that the dog's mouth was dripping with purple saliva. The dog had strayed away, since he was not interested in the conversation, and had bitten into a shellfish on the beach, *Murex trunculus* was its name, though probably none of the three knew it. Hercules tried to resume the conversation where it had been interrupted, but the nymph's eyes were fixed, as though fascinated, on the dog's mouth. Finally she turned to her suitor and said, "I tell you what, Herky, I'll say 'yes' to you, if you will dye me a dress of the lovely purple of that dog's tongue." Probably she said it to get rid of him, but you know Hercules was not the man to take a dare. So he set to



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DEDICATION OF THE NEW BUILDING OF THE NATIONAL ACADEMY OF SCIENCES

President Coolidge addressing the meeting of the National Academy of Sciences on April 28, when the new building in Washington was dedicated. On the left is Professor A. A. Michelson, professor of physics at the University of Chicago, president of the academy. On the right are the three speakers in addition to President Coolidge—Dr. John C. Merriam, president of the Carnegie Institution and vice-president of the academy; Dr. Vernon Kellogg, secretary of the National Research Council, and Dr. Gano Dunn, chairman of the National Research Council.

work to get out the new dye, and it proved to be one of the hardest of the labors of Hercules. For he had to pick out from each shell the tiny sac that contains a few drops of the liquid from which the dye stuff is extracted. But finally Hercules succeeded in dyeing a robe in royal purple to the satisfaction of his lady love and she fulfilled her promise. Presumably, although the legend does not definitely say, they were married and lived happily ever after. At any rate the city that was founded on the industry thus inaugurated took from her its name of Tyre, and made Hercules its patron.

Now for the story of the Twin City, Sidon. A galley of Phoenician merchants were skirting the Syrian coast with a cargo of natrium, that is, natural carbonate of soda, doubtless mixed with lime. It came dinner time and it not being safe or handy to build a fire on board the row boat, they tied up to the shore of the mouth of the river Belus. But where they landed was a sandy beach and not a stone was to be found on which to set the kettle. So one of the men went back to the boat and got some blocks of the natrium and with them built up a rude stove on which to support the cooking utensils. The fire must have been a hot one for when the merchants packed up they found that the sand and soda had fused together to form a new and pretty substance, glass. Having a keen eye for marketable curiosities, they started in the glass business and on this chemical industry was founded the city of Sidon. The Phoenician merchants found that glass beads would readily pass as currency with savages, such as the British. From them they got tin in exchange, which, mixed with nine parts of copper, made the best of bronze for their weapons or ornaments.

Now these stories may be fiction, but they are really fable, for they convey the fundamental fact that these, the Twin Cities of Tyre and Sidon, the richest and most prosperous of their time, were built up on the two great branches of chemical industries, metallurgy and dyeing. They ran their own lines of ships and worked their own mines of gold and galena in Spain, of sulfur and alum in Melos. They imported raw silk and cotton from India and wove and dyed themselves so as to get the profit of the entire process.

If you will refer to the first Book of Kings or the Second Book of Chronicles, you will see how much Hiram, King of Tyre, contributed to Solomon's temple by the chemical arts of his people. The Phoenician ships served as shuttles to bind the nations together by mutual commerce and a common alphabet.

TWO THOUSAND TIMES SWEETER THAN SUGAR

If you find that you have to order sugar oftener than you like, just tell or telephone the grocer to send up a pound of alpha-anti-aldoxine of perillaldehyde. If he fills the bill you will find that this single pound will go as far as a ton of common sugar, and is likely to last the family some twenty years by which time the price of sugar may have fallen to a reasonable level.

Probably the grocer will say, as usual, that he is just out, but has something just as good. Which, as usual, will not be true, because there is nothing just as good, or at least none has yet been discovered, or anyhow been tasted. For, curiously enough, the above-mentioned compound, whose name I shall not repeat since space is short, was known ten years before anybody thought of tasting it. It was first made in Germany in 1910 and duly analyzed and described. But chemists are not in the habit of licking off their fingers whenever they get something on them in the laboratory. If a freshman student has that propensity he gets cured of it before the

end of the term without the teacher's saying a word to him about it. So it was not until 1920 that a chemist, making the aforesaid compound, found to his surprise that it was sweet, and surprisingly sweet at that. He was a Japanese named Furukawa, and I don't know whether he licked his fingers or not, but if he did it was a lucky lick, for he rushed off to the patent office and got the stuff patented as a sweetener. It is made from the essential oil of a plant known to the Japanese as "Shiso" and to botanists as "Perilla."

The interesting thing about it from a chemical standpoint is that it is not in the least like any of the natural sugars in structure, although it is composed of the same elements, carbon, hydrogen and oxygen, the common elements of all foods. Yet if the same number of atoms of the same elements, attached to one another in the same way, are arranged in a slightly different position the resulting compound is not sweet at all.

The record for sweetness has hitherto been held by saccharin, which was made by Ira Remsen, afterwards president of Johns Hopkins University, while he was a student. It is a coal-tar derivative, and also no relation of the sugars, yet it is several hundred times sweeter than cane sugar. Just how much sweeter depends upon the degree of dilution. If the water solution is strong, one part of saccharin equals 200 parts of sugar. If more water is added the sugar solution loses its sweetness in proportion to the dilution, but the saccharin holds out better so that 700 times as much water can be added to the saccharin solution as to the sugar solution before it ceases to taste sweet.

Dulcin, another coal-tar compound, is about half as sweet as saccharin, yet, strange to say, the addition to saccharin of only 50 per cent. of dulcin will nearly double its sweetness. A third coal-tar compound, about a hundred times as sweet as sugar, goes under the name of glucin.

Another super-sweet was reported at the recent meeting of the American Chemical Society by A. W. Dox and Bruce Houston, of Detroit. This is some 300 times sweeter than sugar and is altogether unlike any of the others in structure. It contains chlorine and is called "hexyl-chloro-malonamide," but if it is ever made marketable, it must be given a name that is less of a mouthful. A slight change in the make-up of its molecule produces a compound that is not sweet but intensely bitter. The tongue is a good chemist. Yet, having been trained through thousands of years by the tasting of fruits where sweetness usually means wholesome nutriment, it is fooled by these new compounds, which are much more sweet but not nutritious at all. Still they have been found convenient for diabetics who can not digest sugar and in a case of war when sugar costs too much.

The discovery of these synthetic sweets raises embarrassing questions in love and literature. In courtship nothing less than superlatives will pass current and no self-respecting maiden will feel flattered to be called "honey" or told that she is "sweet as sugar" when she knows that there are similes far sweeter. Many of our girls are studying chemistry now-a-days and know too much to accept inferior substitutes in candy or compliments. Chemical names do not fit easily into verse, even when verse is most free and freaky. But doubtless a tabloid trade form will be devised, such as "saccharin," "dulcin" and "glucin." The compound that I mentioned first, the Japanese one, could be condensed to "peri" or "perilla." The former has already acquired poetical connotation through Moore's "Peri outside Paradise," but the latter would fit more neatly into valentine rimes, such as

The rose is red, the violet blue,
Perilla's sweet, and so are you.